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# Dynamics of dissolved organic carbon during weathering and soil formation

Kimberly Linnea McCracken
*University of New Hampshire, Durham*

# DYNAMICS OF DISSOLVED ORGANIC CARBON DURING WEATHERING AND SOIL FORMATION

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Kimberly L. McCracken
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M.S. Natural Resources – Soil Science, University of New Hampshire, 1994

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UMI
300 North Zeeb Road
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This dissertation has been examined and approved.

Dissertation Director, William McDowell,
Associate Professor of Water Resources

Robert Harter,
Professor of Soil Chemistry

Scott Bailey, USDA Forest Service
Research Geologist

Rakesh Minocha, USDA Forest Service
Research Biochemist

Daniel Zarin,
Assistant Professor of Forest Ecology

4-27-98

Date

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TABLE OF CONTENTS

ACKNOWLEDGMENTS ........ iii

LIST OF TABLES ........ vi

LIST OF FIGURES ........ vii

ABSTRACT ........ ix

INTRODUCTION ........ 1

CHAPTER I. EFFECTS OF DOC CONCENTRATION ON METAL AND SILICA RELEASE ... 5

INTRODUCTION ........ 5
MATERIALS AND METHODS ........ 7
*Soil characteristics* ........ 7
*Experimental procedure* ........ 7
RESULTS ........ 10
*Influence of DOC concentration on element release* ........ 10
*Element mobility during early stages of weathering* ........ 12
*Soil properties controlling release* ........ 13
DISCUSSION ........ 13

CHAPTER II. EFFECTS OF DOC CONCENTRATION ON ABUNDANCE AND CHEMICAL COMPOSITION OF GRAIN COATINGS ........ 33

INTRODUCTION ........ 33
MATERIALS AND METHODS ........ 34
*Soil characteristics* ........ 34
*Dissolved organic carbon solution* ........ 34
*Experimental procedure* ........ 35
RESULTS ........ 36
*Soil chemistry* ........ 36
*Micromorphology* ........ 38
*Relationships between soil chemistry and solution chemistry* ........ 39
DISCUSSION ........ 39

CHAPTER III. INFLUENCES OF SOIL CHEMICAL AND PHYSICAL PROPERTIES ON DOC CONCENTRATIONS IN FOREST SOILS ........ 61

INTRODUCTION ........ 61
MATERIALS AND METHODS ........ 63
*Dissolved organic carbon* ........ 63
*Experiment 1. Controls on DOC concentration in the soil profile* ........ 64
*Experiment 2. Soil surface area control of DOC retention* ........ 65

*Sorption experiments*......66
RESULTS......67
*Experiment 1*......67
*Experiment 2*......69
DISCUSSION......70
LITERATURE CITED......91
APPENDIX A (COLUMN STUDY)......99
APPENDIX B (BATCH AND FIELD STUDIES)......132

## LIST OF TABLES


TABLE PAGE

1-1. Parent material characteristics . . . . . . . . . . . . . . . . . . . . . . . . . . . . 19

1-2. Soil material particle size distribution . . . . . . . . . . . . . . . . . . . . . . . . . . 20

1-3. Mean concentration of DOC in the input solutions . . . . . . . . . . . . . . . . . . . 21

1-4. Molar ratios of net Al and Si release . . . . . . . . . . . . . . . . . . . . . . . . . . . 22

1-5. Percent element mobility . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 23

1-6. Element mobility series rankings . . . . . . . . . . . . . . . . . . . . . . . . . . . . 24

1-7. Mean pH of input and outflow solutions . . . . . . . . . . . . . . . . . . . . . . . . 25

1-8. Element mobility and parent material chemical composition . . . . . . . . . . . . . 26

2-1. Selected characteristics of the parent materials . . . . . . . . . . . . . . . . . . . . . 44

2-2. Chemical composition, surface area and particle size distribution . . . . . . . . . . . 45

2-3. Chemical extractions of the soil materials . . . . . . . . . . . . . . . . . . . . . . . . 46

2-4. Cumulative release or retention of solution constituents following leaching . . . . . 47

3-1. Physical and chemical characteristics of the field experiment soil materials . . . . 77

3-2. Batch parameters for field experiment soil materials. . . . . . . . . . . . . . . . . . . 78

3-3. Chemistry of soil lysimeter solutions . . . . . . . . . . . . . . . . . . . . . . . . . . 79

3-4. Physical and chemical characteristics of the soils (Experiment 2) . . . . . . . . . . . 80

3-5. Extractable quantities of Al and Fe of the soils (Experiment 2) . . . . . . . . . . . . 81

3-6. Batch parameters for surface area experiments . . . . . . . . . . . . . . . . . . . . . 82

3-7. DOC concentrations in soil solution from several locations . . . . . . . . . . . . . . 83

# LIST OF FIGURES

FIGURE PAGE


1-1. Release of Si and Al . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 27

1-2. Relationship between Al and Si release. . . . . . . . . . . . . . . . . . . . . . . . . . . 28

1-3. Release of Mg and Ca . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 29

1-4. Release of Fe . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 30

1-5. DOC retention . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 31

1-6. Relationships between pH and Al release . . . . . . . . . . . . . . . . . . . . . . . . 32

2-1. Column study set-up . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 48

2-2. Chemical analysis: Soil pH . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 49

2-3. Chemical analysis: Percent loss-on-ignition . . . . . . . . . . . . . . . . . . . . . . . 50

2-4 Photomicrograph – Nitric acid treatment . . . . . . . . . . . . . . . . . . . . . . . . . 51

2-5 Photomicrograph – Forest floor low treatment . . . . . . . . . . . . . . . . . . . . . . 52

2-6 Photomicrograph – Forest floor high treatment . . . . . . . . . . . . . . . . . . . . . 53

2-7 Abundance of grain coatings following leaching . . . . . . . . . . . . . . . . . . . . 54

2-8 Abundance of cutans and measures of soil organic carbon . . . . . . . . . . . . . . 55

2-9 Relationship between DOC retention and abundance of grain coatings . . . . . . . 56

2-10 Solution and soil measures of organic carbon retention . . . . . . . . . . . . . . . . 57

2-11 Distribution of Al release . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 58

2-12 Distribution of Si release . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 59

2-13 Distribution of Fe release . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 60

3-1. Initial mass isotherms for selected soil horizons from Experiment 1 . . . . . . . . . . 84

3-2. Equilibrium DOC concentrations in the soil profile . . . . . . . . . . . . . . . . . . . . 85

3-3. Relationships between sorption parameters and soil chemical properties . . . . . . 86

3-4. Relationship between % organic carbon and DOC release from soil horizons . . . 87

3-5. Initial mass isotherms for soil materials from Experiment 2 . . . . . . . . . . . . . . 88

3-6. Relationship between $DOC_{np}$ and $Fe_d$ . . . . . . . . . . . . . . . . . . . . . . . . . . . 89

3-7. Trends in DOC concentrations in the soil profile . . . . . . . . . . . . . . . . . . . . . 90

ABSTRACT

DYNAMICS OF DISSOLVED ORGANIC CARBON DURING
WEATHERING AND SOIL FORMATION

by

Kimberly L. McCracken
University of New Hampshire, May 1998

Interactions between dissolved organic carbon (DOC) and mineral soils were examined in field and laboratory experiments. Specific emphasis was given to factors influencing DOC mobility and element release during mineral weathering and soil formation. Soil chemical and physical properties controlling equilibrium concentrations of DOC ($DOC_{np}$) in coarse-textured forest soils were investigated using laboratory batch reactors and the initial mass isotherm approach. The influence of DOC concentration on release of metals and silica was investigated in four soil parent materials. One of four acid treatments (0.001 N $HNO_3$ and three concentrations of forest floor leachate) or distilled water were added to soil columns every third day for one year. Chemical composition of solutions and soil materials were analyzed before and after solution percolation to assess net release or retention of DOC and inorganic constituents. Results of laboratory column and batch investigations were compared to trends in weathering and DOC retention in a field site in Berlin, NH. In soil B horizons, $DOC_{np}$ was correlated with soil pH, % OC, and some forms of extractable Al and Fe. Soil properties correlated with $DOC_{np}$ values in B horizon soils were not generally correlated the $DOC_{np}$ values in E horizons. $DOC_{np}$ values were not correlated with soil surface area. Laboratory derived trends in $DOC_{np}$ values were in agreement with patterns of DOC concentrations in field soil solutions. In the column study, release of Si, Al, Ca, and Mg from soil materials increased with increasing DOC input. Changes in soil chemical properties (pH, loss-on-ignition, extractable Al and Fe) following leaching were consistent with podzolization. The most dramatic changes in soil chemical properties were

found in soils leached with high concentrations of DOC. Comparison of solution and soil measures of organic carbon retention indicate that only about 50% of the DOC lost from solution was measured as soil organic carbon at the end of the experiment. This finding shows that microbial decomposition is a significant factor regulating organic carbon concentrations in mineral soils and that soil solution data alone do not yield a complete picture of organic carbon dynamics.

# INTRODUCTION

On an ecosystem level, dissolved organic carbon (DOC) functions in many chemical, physical and biological processes. DOC is comprised of a wide range of organic compounds including carbohydrates, proteins and low molecular weight organic acids as well as humic and fulvic acids. In forest ecosystems, sources of DOC include plants and animals and their waste products. DOC concentration in soil solution may be an indicator of resource availability for microbial growth and biological decomposition (Cook and Allan 1992; Qualls and Haines 1992). Studies from around the globe indicate that the majority of DOC in mineral soils originates from the forest floor (Ugolini et al. 1987, 1988; McDowell and Likens 1988; Moore 1989; Edmonds et al. 1991; Dalva and Moore 1991; Easthouse et al. 1992; Guggenberger and Zech 1993), but additional DOC may be produced from roots and indigenous organic carbon in mineral soil (Smith 1976; Edwards and Harris 1977; Raich and Nadelhoffer 1989; Ochs et al. 1993).

DOC in mineral soils may be exported to groundwater or surface waters, utilized by microbes or retained in the mineral soil by abiotic mechanisms. It is generally accepted that DOC concentrations decline with depth in mineral soils as a result of DOC retention by soil surfaces (McDowell and Likens 1988; Moore et al. 1992; Qualls and Haines 1992; Vance and David 1992; Donald et al. 1993). Qualls and Haines (1992) concluded that abiotic retention of DOC was primarily responsible for the reduction in DOC concentrations because biological decomposition was too slow to account for the large reduction in DOC concentrations observed in field studies. They noted, however, that decomposers may facilitate adsorption processes by removing organic compounds held on the exchange complex, thereby opening more sites for additional adsorption (Qualls and Haines 1992; Bohn et al. 1985). Their work corroborated early work by McDowell and Wood (1984), who also concluded that abiotic adsorption was largely responsible for DOC retention. Most investigations of DOC retention have focused entirely on changes in the concentration of DOC in soil solution. Coupling examination of soil solution chemistry with soil chemistry may enhance understanding of the mechanisms of DOC retention in forest soils.

Soil surface area and mineralogy, coupled with soil-solution contact time, have been proposed as major factors regulating DOC retention by mineral soils (Vance and David 1992; Easthouse et al. 1992; Lundstrom 1993; Nelson et al. 1993). Fahey and Yavitt (1988) noted that retention of DOC was positively correlated with clay content, whereas soils with high amounts of sand adsorbed little DOC or other anions. Mayer (1994 a, b) suggests that the organic carbon content of soils and sediments is related to the surface area of the materials. The monolayer equivalent, a single layer of carbon covering all mineral surfaces, has been calculated to be equivalent to 0.86 mg carbon per square meter of soil mineral surface area (Mayer 1994b). With increased contact time, DOC concentration in mineral soil solutions tends to decrease until equilibrium is established (Rustad et al. 1993). DOC retention has been correlated to HCl-extractable Fe and Al (McDowell and Wood 1984), oxalate-extractable Al and Fe (Dalva and Moore 1991), dithionite-extractable Fe (Jardine et al. 1989) and amorphous Al and Si surface coatings on phyllosilicates (Jardine et al. 1989; Schultless and Huang 1990). However, no study has examined whether surface chemistry, mineralogy or surface area is the factor controlling DOC adsorption. Additionally, because the clay-sized fraction is typically enriched in phyllosilicates and sesquioxides (Bohn et al. 1985) it becomes exceedingly difficult to distinguish the influence of mineralogy and surface chemistry from surface area in the field.

DOC in terrestrial ecosystems supplies energy and nutrients to microbes (Cook and Allan 1992; Qualls and Haines 1992), and functions in acid-base reactions, metal-complexation, mineral weathering and soil formation (Wright and Schnitzer 1963; Graustein et al 1977; Antweiler and Drever 1983; McDowell and Wood 1984). Organic acids influence mineral weathering (Graustein et al. 1977; Antweiler and Drever 1983) and soil formation by way of their contribution to soil solution pH and complexing capabilities (Wright and Schnitzer 1963; Drever and Vance 1994). Due to its strong chelation abilities, DOC may be an essential agent in the formation of

Spodosols, which are characterized by accumulation of metals and organic carbon in B horizons (McKeague et al. 1983). Availability of nutrients and toxic substances to plants is affected by the ability of soils to remove dissolved substances from solution (Reuter and Perdue 1977; McDowell and Likens 1988; Moore 1989; Qualls et al. 1991; Donald et al. 1993). The strong complexing capabilities of DOC make it a significant agent for many geochemical reactions and associations with potentially toxic metals such as iron, aluminum, copper and mercury (Stevenson 1985; Thurman 1985; Jardine et al. 1990; Schiff et al. 1990) and radionuclides (Means et al. 1978; Sheppard et al. 1980). Soluble organic compounds can serve as carriers for adsorbed or chelated compounds that are transported through soil and may end up in groundwater and surface waters (Dawson et al. 1978; McCarthy and Zachara 1989; Dunnivant et al. 1992; Guggenberger et al. 1994; Murphy and Zachara 1995). Dispersal of inorganic and organic chemical contaminants may also be associated with DOC. The movement of DOC in soils may facilitate transport of hydrophobic organic compounds such as chlorinated hydrocarbons and DDT (Thurman 1985; Jardine et al. 1989, 1990), and thus has important environmental implications. Chelation of trace metals by DOC can increase the bioavailability of some metals ($Fe^{3+}$) and decrease the toxicity of others ($Al^{3+}$) (Wolt 1994). Because of the important role DOC plays in the transport of metals and contaminants, there is a need to better understand the mechanisms controlling the mobility of DOC in soils, sediments and groundwaters in a variety of systems (Santore et al. 1995; Sollins et al. 1996).

Dissolved organic carbon (DOC) in terrestrial ecosystems is a source of energy for microorganisms and also functions as a transport mechanism for metals and potential toxins in the soil profile. Both ecologists and pedologists have studied the dynamics of DOC in the soil profile, but the limited integration of the two disciplines has resulted in an incomplete understanding of the role of DOC in soils, and the effect of soils on DOC mobility in terrestrial ecosystems. This work attempts to bridge that gap by measuring DOC, Al, Fe, and Si concentrations in soil profiles and examining interactions among these constituents in laboratory settings. The experiments include monitoring and assessing current and long-term processes in the field as well as controlled laboratory column and batch studies that focus on elucidating mechanisms that can not be isolated in the field. Additionally, this hierarchy of control levels allows for assessment of the validity of applying laboratory results to a field setting.

# CHAPTER I.

## EFFECTS OF DISSOLVED ORGANIC CARBON CONCENTRATION ON METAL AND SILICA RELEASE

### Introduction

The role of organic acids during weathering and soil formation has been debated for the last century (Julien 1879; Clarke 1911; Graham 1941; Wright and Schnitzer 1969; Baker 1972; Bennett and Siegel 1987; 1990; Bennett and Casey 1994; Drever and Vance 1994; Drever and Stillings 1997). Results of many studies suggest that some organic acids have no effect on weathering or may inhibit mineral dissolution (Krauskopf 1967; Lundström and Öhman 1990; Ochs et al. 1993). Studies by Lundström and Öhman (1990) and Ochs et al. (1993) indicate that high molecular weight humic acids may inhibit weathering even under acidic conditions (pH 4). Bennett et al. (1988) examined the abilities of organic acids to form complexes with silica and found that some organic acids do form complexes with silica (citric, oxalic and pyruvic acids) whereas no complexation occurred with other organic acids (acetic, lactic, malonic and succinic acids). Other studies have shown mineral weathering increases in the presence of organic solutes (Graustein et al. 1977; Antweiler and Drever 1983; Bennett et al. 1988; Lundstrom et al. 1995). The increased acidity and complexing capabilities associated with organic acids are thought to be responsible for the increase in weathering (Wright and Schnitzer 1963; Tan 1986; Bennett and Siegel 1987; Drever and Vance 1994). Huang and Keller (1970), examining initial release of silica and metals from fresh mineral surfaces, concluded that relative to water, release of Al, Fe, Si, Ca and Mg was enhanced in the presence of organic acids. Additionally, Huang and Keller (1970) suggest that higher release rates of Al and Fe compared to silica were attributable to complexation of Al and Fe via organic acids. McColl and Pohlman (1986) investigated the influence of citric acid and nitric acid at pH 3 on release of Al, Fe and Mn from soil A horizons and concluded that proton-promoted dissolution alone could not account for the release of these constituents. Tan (1980) examined the release of Si and Al with fulvic acids at pH 7.0 and pH 2.5, as well as water at pH 2.5. The increased acidity in the pH 2.5 water treatments resulted in a higher release of Al and Fe in microcline relative to the pH 7.0 fulvic acid treatment. The pH 2.5 fulvic acid treatment released significantly more Al and Fe than the pH 7.0 fulvic acids, suggesting that pH is not the only factor contributing to increased dissolution.

Previous investigations have provided much useful information concerning the role of DOC and organic acids during weathering. However it is questionable whether results of these laboratory investigations can be applied to minerals weathering in natural conditions (Casey et al. 1993; Courchesne et al. 1996) due to the type of soil materials investigated (mono-mineral systems), condition of the mineral surfaces (freshly exposed surfaces created by grinding, crushing or harsh chemical pre-treatments) and the composition of the weathering solutions (purified humic, fulvic and low molecular weight organic acids or single low molecular weight organic acids). Extreme departures from natural weathering conditions, where most weathering occurs in heterogeneous environments, may limit application of these results to natural systems.

The objectives of this study were to (1) determine if natural, heterogeneous DOC increases the release of metals and silica from soil materials; (2) quantify release of metals and silica during early stages of weathering; and (3) determine if soil properties are related to release and retention of these constituents. Additional goals of the study were to compare initial weathering in four parent materials while minimizing common differences between laboratory and field investigations by using natural heterogeneous solutions and by not pre-treating the soils with strong acids/bases or grinding the materials. Several investigators have pointed out the need for closing the gap between parameters in the laboratory and field studies (Davis 1982; Casey et al. 1993; Santore et al. 1995; Courchesne et al. 1996). Reducing differences between laboratory and field investigations of weathering will allow for an improved application of laboratory results to field settings and therefore a better understanding of field weathering rates and biogeochemical cycles.

## Materials and Methods

### Soil Characteristics

Soil materials were collected from four locations in order to vary lithologic composition. Each sample is also the parent material of a Spodosol series in New Hampshire. The Hermon parent material was collected from the C horizon of a soil pit. The Marlow and Success parent materials were collected by digging horizontally into C horizons of road-cuts. The Lombard parent material was collected from the IICr of a road-cut. Mineralogy and chemical composition of the parent materials were determined using a Siemens Kristalloflex Diffraktometer D5000 and X-ray fluorescence spectroscopy (XRAL Activation Services Inc., Ann Arbor, MI), respectively. BET soil surface area was measured using a krypton adsorbate (Micromeritics Instrument Corp., Norcross, GA). Samples have similar $SiO_2$ and $Al_2O_3$ content and vary primarily in surface area, and content of CaO, MgO and $Fe_2O_3$ (Table 1-1; also see Appendix A). The Lombard parent material may also contain a small amount of carbonate minerals (Hatch 1963). The Hermon parent material is the coarsest of the four parent materials, and the Marlow has the highest content of fine grains (Table 1-2). The Lombard parent material is derived from phyllite that ranges from easy to moderately difficult to crush by hand. The fragile nature of this material makes measurements of particle size distribution and surface area of the Lombard samples only approximate measurements.

### Experimental Procedure

One hundred and ninety grams (mean soil depth = 32 mm) of air-dried soil (0.053 mm - 11.2 mm) was packed into Falcon Bottle Top Filter units with a 38μm nylon filter in the bottom outlet. The <0.053 mm fraction was removed by dry sieving to reduce the likelihood of filter clogging over the course of the experiment. In an investigation examining the use of laboratory column and batch techniques to measure weathering rates, sieving and column packing were shown to have minimal influence on weathering rates (Van Grinsven and Van Riemsdijk 1992). The soil columns in this investigation were kept under a laboratory hood to prevent air-borne contamination. Small pillows made from plastic mesh were constructed to disperse the solutions as they were poured onto the columns.

Effects of five solution treatments were evaluated – distilled water, 0.001 N nitric acid and three concentrations of forest floor leachate. Triplicate samples of each parent material were prepared for each treatment for a total of 60 columns. Forest floor material, collected in October 1994 and August 1995 from a coniferous forest in Durham, NH, was refrigerated until used to make leachate solution. Forest floor leachate (FF) for each solution addition was freshly made by placing 840g of forest floor litter in 4.2 L of distilled water for six days. The forest floor-water slurry was stirred every day to reaerate the solution and filtered (38 μm nylon filter, 0.45 μm cellulose nitrate filter) prior to application. Three concentrations of FF were used: high (full strength), medium (1:1 FF to distilled water) and low (1:9 FF to distilled water). A sample of each input solution was saved to determine DOC concentration (Appendix A). The mean concentration of DOC in the FF-high input solution for the five treatment periods ranged from 12.1 to 43.6 mmol C/L (Table 1-3). The general trend of increasing DOC concentration from the beginning of the experiment through day 238 may be explained by decomposition of the forest floor material during storage. The decreased concentration of DOC beginning at day 238 of the investigation corresponds with the use of forest floor material collected in August 1995. The pH of the FF input solutions was somewhat variable. The mean pH values of the input FF solutions were: low = 4.6 (range 3.8 to 5.6), medium = 4.2 (range 3.5 - 5.2), and high = 4.1 (range 3.3 to 5.0). The normality of the $HNO_3$ (0.001 N, pH 3) was selected as a lower bound for the pH of the forest floor leachates. Mean concentrations (μmol/L) of cations in the FF-high solution were: Si, 150.8; Fe, 50.5; Al, 102.5; Ca, 236.3; and Mg, 74.7 (See Appendix A).

Packed columns received 100 mL of solution (equivalent to 34 mm) every three days for 1 year; cumulative solution addition was 4000 mm. DOC, Si, Al, Fe, Ca and Mg were measured in solution samples collected before and after percolation through the soil column. Solution samples for DOC analysis were frozen; solution samples for analysis of other constituents were refrigerated. Organic carbon content of leachate solutions was measured using a Shimadzu TOC 5000 Total Organic Carbon Analyzer (high temperature Pt-catalyzed combustion). Dissolved silica was determined using the molybdate-blue method (Strickland and Parsons 1968). Total Al, Fe, Ca, and Mg were measured using Beckman Direct Current Plasma Emission Spectroscopy (DCP). Percent water yield following the first solution addition was $84 \pm 5$, $84 \pm 6$, $84 \pm 6$, and $78 \pm 8$ for the Hermon, Marlow, Success and Lombard materials, respectively. Two 1 mL subsamples of the outflow from the last four solution collections were collected for each leaching event for determination of DOC (samples frozen) and inorganic constituents (samples refrigerated). The subsamples for individual replicates were bulk sampled. The solution chemistry was analyzed five times during the course of the experiment: days 69, 165, 228, 285, and 357, corresponding to 2.3, 3.2, 2.1, 1.9 and 2.4 L of solution passed through each column, respectively. The outflow from the first collection period was not bulk sampled; a single outflow sample was collected after 23 solution additions (See Appendix A).

Measurements of the relative mobility of different mineral constituents have been used extensively in studies of groundwater and springwater. The mobility series is determined by calculating the weight fraction of the total dissolved matter that is made up of a given element divided by the weight fraction of the same element in the material being weathered (Berner and Berner 1996). Due to the net retention (loss from solution) of some constituents in this investigation, the standard method of determining relative mobility of elements could not be used. Therefore, the term element mobility (EM), a measure of the release of a constituent to solution relative to its abundance in the initial soil material, was calculated for each parent material-solution addition treatment combination for Si, Al, Fe, Ca, and Mg as follows:

$$EM_Y = \frac{\text{net moles Y released to solution}}{\text{moles Y in original parent material}} \times 100$$

where Y = element of interest. The five elements were ranked 1 (lowest release) to 5 (highest release) for each treatment to obtain the relative order of mobility for the treatment. EM rankings were averaged across solution type and parent material to obtain the release order for each parent material and solution treatment, respectively.

Differences between parent material/solution treatments were determined using ANOVA with Bonferroni multiple comparison test. Relationships among element release patterns were assessed using Pearson's correlation. Element release and soil physical and chemical properties were examined with linear regression. For all statistical analyses, a significance level of $p \leq 0.05$ was used.

## Results

### Influence of DOC Concentration on Element Release

Release patterns for Si and Al were similar (Figure 1-1; see Appendix A for raw outflow solution data) across parent materials and treatments, although absolute quantities of Al released were much higher than Si. Net release (concentration of constituent in outflow solution – concentration of constituent in input solution) of both ions increased with increasing DOC input. The medium and high levels of FF and the 0.001 N $HNO_3$ treatments all released significantly more Si than the DW treatment of the same parent material (Figure 1-1). The nitric acid and FF-high treatments resulted in a high loss of Al (> 7.8 μmol Al per gram of soil) from all parent materials except Lombard ( ≤ 3.8 μmol Al per gram of soil), which has the lowest Al content (Figure 1-1). The Al release from the FF-high and the nitric acid treatments were statistically indistinguishable for the Hermon and Success parent materials. In the Marlow, the nitric acid treatment released significantly more Al (15.1 μmol Al per gram of soil) than the FF-high treatment (10.9 μmol Al per gram of soil), and in the Lombard, the FF-high treatment released significantly more Al (3.8 μmol Al per gram of soil) than the nitric acid treatment (0.66 μmol Al per gram of soil).

There was a strong relationship (r = 0.83) between net release of Al and net release of Si (Figure 1-2) for distilled water and all FF treatments during early stages of weathering. The relationship was not as strong when the nitric acid treatments were included (r = 0.62). The Al:Si ratios for the distilled water and FF-low treatments were all below 2:1 (Table 1-4). The nitric acid treatment resulted in a much higher Al:Si molar ratio (>3.3) for the Hermon, Marlow, and Success soils and a much lower ratio (0.13) for the Lombard parent material. The Al:Si ratios for the FF-medium (1.91 to 2.39) and FF-high (1.86 to 2.38) treatments for the Hermon, Marlow and Success parent materials were all close to 2:1, but the Lombard Al:Si ratios for the FF-medium (0.68) and FF-high (0.68) treatments were much lower.

Net release trends for Ca and Mg were similar to those of Al and Si, showing a direct relationship between net release and DOC concentration in the input solution. The nitric acid treatment released very small amounts of Mg ($\leq$ 0.11 µmol Mg per gram of soil), similar to DW treatment, in all parent materials except the Lombard where significantly more Mg was released than from any other treatment, 6.3 µmol Mg per gram of soil (Figure 1-3). The Ca release was typically higher from the nitric acid treatments than the other solutions, except for the Hermon where it was very low, approximately equal to the FF-low treatment (Figure 1-3). The Lombard parent material released significantly more Ca than the other parent materials for the nitric acid (18.3 µmol Ca per gram of soil) and FF treatments. There was a very strong direct relationship between net release of Ca and Mg (r = 0.98) for all parent materials and solution treatments.

Iron displayed some of the most complex release trends (Figure 1-4). In several FF treatments, there was a net retention of iron (input > net output). The FF-low solution treatment resulted in net retention of Fe in all parent materials (0.07 to 0.16 µmol Fe retained per gram of soil). All materials except Lombard retained Fe when leached with the FF-medium solution. The FF-high treatment released Fe from all materials except Marlow. The Lombard FF-high treatment released significantly more Fe (2.3 µmol Fe per gram of soil) than the other materials (range -0.7 to 0.4 µmol Fe per gram of soil). The relationship between net release of Fe and Al was very poor (r = 0.003).

All materials retained DOC at all levels of FF treatment, and all materials retained less DOC under FF-low concentrations (Figure 1-5). For Hermon, Marlow and Success materials, percent retention of DOC decreased with increased input of DOC (Figure 1-5). Net retention differences between the FF-medium and FF-high treatments were not significant. The Lombard material retained significantly more DOC (245 μmol C per gram of soil) than the other three materials (≤ 158 μmol C per gram of soil) leached with FF-high. This difference is consistent with the higher surface area of the Lombard material. There was only a moderate relationship between net retention of DOC and Fe ($r = 0.44$).

Element Mobility During Early Stages of Weathering

Ca had the highest percentage of element mobility (EM) (Table 1-5) ranging from 0.04 to 5.22. EM values for Fe were the lowest, ranging from -0.225 to 0.464. When all solution treatments are grouped together for each parent material, there was little difference in EM rankings (Table 1-6):

$$Fe < Si < Al < Mg < Ca$$

In the Lombard material, the relative positions of Al and Si were reversed. With little difference among parent materials, solution effects were examined by grouping all of the parent materials together (Table 1-6). The magnitude of release for the DW treatment is the same relative magnitude of release described by Feth et al. (1964) to describe release of constituents during primary rock weathering from examination of groundwater chemistry. The $HNO_3$ (pH = 3) mobilized Al as efficiently as Mg. When compared to water, DOC increased Al and Fe mobility but decreased the relative mobility of Si.

The pH values of the input and outflow solutions (Table 1-7) are also important factors controlling element mobility. Solutions percolating through the Lombard parent material have pH values 0.1 - 0.7 pH units higher than the other parent materials with the same solution treatment. The nitric acid (pH = 3.0), and FF high (pH = 4.1) treatments for the Lombard parent material released significantly less Al than the other parent materials with the same input solution pH (Figure 1-6a). There was a moderate relationship between net Al release and pH of input and outflow solutions ($r^2$ = 0.466 and 0.475, respectively). Both relationships were improved when the Lombard parent material was not included (pH input vs. Al, $r^2$ = 0.723; pH outflow vs. Al, $r^2$ = 0.611).

Soil Properties Controlling Release

The relationship between net element release and the oxide percent of each cation in the four parent materials was described using a best fit line for each solution treatment. Due to the small number of points in each regression (n = 4) few relationships were significant at the $p \leq 0.05$ level (Table 1-8): Mg release from all solution treatments except DW (positive relationships), and Fe release for $HNO_3$ (negative relationship) and FF-high (positive relationship). Net release of Si, Fe, Ca and Mg generally increased with increased surface area of the parent materials. The net release of Al showed no clear trend with surface area except that the material with the highest surface area, Lombard, consistently had the lowest net release of Al. The Lombard material also has the lowest percent $Al_2O_3$ of the four materials (13.1 %). However, with limited surface area data – one measurement for each of the pre-treatment parent materials – as well as the fragile nature of the Lombard parent materials, the role of surface area in net release remains unclear. Retention of DOC in the FF-high treatments was correlated with surface area ($r^2$ = 0.93). DOC retention in the FF-medium and FF-low treatments was not related to surface area.

## Discussion

Results of this investigation show that heterogeneous DOC solutions increase the release of Al, Si, Ca and Mg in a variety of soil parent materials, relative to distilled water. Additionally, the magnitude of release increased with increasing DOC concentrations in the leaching solutions. The findings of this study are in agreement with earlier comparisons between the effects of proton- and ligand-promoted dissolution (Huang and Keller 1970; Tan 1980; McColl and Pohlman 1986), which indicate that the accelerated weathering caused by organic acids can be attributed to the interaction between increased acidity and chelation effects (Tan 1980; McColl and Pohlman 1986). My results suggest that the acidity associated with FF solutions may be responsible for most of the release of $Al^{+3}$ from the Hermon, Marlow and Success parent materials, with ligand-promoted dissolution being a secondary mechanism. In the Lombard parent material where small quantities of carbonate minerals resulted in higher outflow pH values, chelation may have played a larger role in release of Al than proton-promoted dissolution. However, due to the fluctuation in the pH of the FF solutions, there was no direct pH comparison between the nitric acid and the FF treatments. The nitric acid treatment can be used as a lower bound for the pH of the FF-high solutions. Proton-promoted dissolution is most likely the dominant mobilizing mechanism for Al, yet chelation is also a viable transporting agent for Al, especially at high concentrations of DOC (Figure 1-1b). My results indicate that chelation via organic acids plays a key role in the release and retention of Fe, whereas the acidity of the nitric acid had little impact on the release of Fe (Figure 1-4).

There were few significant trends between the chemical composition of the soil materials and net release of constituents to solution. With only 4 parent materials with similar chemical composition, it is difficult to ascertain whether the net release of Al, Si Ca, Mg, and Fe are attributable to the content of these elements or to the differences in surface area among these materials. Although present only in small quantities in the Lombard parent material, weathering of carbonate minerals may explain the high release rates of Ca and Mg. Additionally, the high loss of Fe from the Lombard parent material may reflect release of Fe from rapid weathering of small amounts of the carbonate minerals siderite and dolomite (Hatch 1963) as well as amorphous Fe-oxide in this saprolite material and therefore may not be attributed to chelation by organic acids. In the case of Al, the chemical and mineralogical composition of the samples seems to exert more control than the surface area of the materials. Despite the narrow range of Al-oxide contents in the four parent materials, there were significant differences in net Al release among parent materials. As with Ca, Mg and Fe, this pattern may also be linked to the presence of small amounts of carbonate minerals. While Al is not likely a constituent of the carbonate minerals, the pH buffering capacity of carbonates can exert significant control over the solubility of Al in the pH ranges encountered during this investigation. These findings support the need for further examination of heterogeneous systems in laboratory settings. As shown in this investigation, the presence of some minerals, even in small quantities, may control release of constituents from other minerals, thereby complicating any attempts to extrapolate from highly simplified laboratory systems to complex field settings.

Soil surface area was not effective in explaining differences in element release or DOC retention among these soil materials. The relationship between DOC retention and soil surface area was only significant in soils leached with the FF-high leachate, although differences in surface area may partially explain the DOC retention pattern in the FF-medium and FF-high treatments. For the Hermon, Marlow and Success soils, there was no significant difference in the amount of DOC retained between the FF-medium and FF-high treatments, despite twice the amount of DOC added to the FF-high soils. This retention pattern may be attributed to reaching a saturation point, or covering the available amount of surface sites with OC. Mayer (1994a, b) has extensively examined the relationship between particle surface area and OC content of soils and sediments. The monolayer equivalent, a single-layer of OC covering all mineral surfaces was calculated to be equivalent to 0.86 mg OC / $m^2$ of soil (Mayer 1994b). The FF-medium and FF-high treatments for the Hermon, Marlow and Success soils are at or near the level of monolayer coverage following the one year of solution treatment. The Lombard materials, with at least twice the surface area of the other soil materials had only 0.48 mg OC/ $m^2$.

Several investigators have examined the influence of surface area on mineral weathering (Velbel 1986, 1990, 1993) and retention of natural DOC (Mayer 1994a, b) and organic contaminants (Barber et al. 1992), yet there does not appear to be a general consensus on the role of surface area in these biogeochemical processes. Velbel (1986, 1993) suggests that many laboratory weathering rates are much higher than field weathering rates because, in the field, not all of the surface area of a soil encounters solutions percolating through the soil profile. Therefore when applying results of laboratory weathering studies to field soils the use of a correction factor between the effective surface area of soils and total surface area may further explain the widely reported discrepancies between laboratory and field weathering rates (Velbel 1986, 1993). If surface area is one of the dominant controls on the release and retention of constituents in the soil/solution system, My results indicate that measures of total surface area do not explain differences in release and retention of soil/solution constituents. Additional data such as quantitative mineralogical data or cation position within the mineral crystal and overall crystal structure (Barman et al. 1992) may further elucidate important controls on element release.

The order of the relative element mobility series for Al, Ca, Fe, Mg and Si, exhibited only minor differences among the four parent materials (Table 1-6). When the element mobility series was examined by grouping the parent materials together and evaluating effects of different solution treatments, several trends were noted (Table 1-6). Compared to the distilled water treatment, leaching with nitric acid resulted in an increase in mobility of Al relative to the other constituents. This increase in Al mobility is likely due to the increased acidity associated with the nitric acid solution, which increases the solubility of Al. The increase in Al mobility relative to distilled water was also noted in all of the DOC treatments. Additionally, in soils treated with high concentrations of DOC, Fe mobility increased and Si became the least mobile constituent. The trend of increased Al and Fe mobility and decreased Si mobility in DOC treated soils is consistent with podzolized soil profiles where there is a residual accumulation of Si-rich material in the E horizon just below the forest floor and a peak in Al and Fe with depth in the profile in the spodic horizon (Bhs and Bs).

The mechanisms of Al and Fe translocation have long been the subject of examination in pedologic investigations of podzolization. The very poor relationship between release of Al and Fe during this investigation is notable as these constituents are frequently combined in discussions of podzolization (Birkeland 1984), although other studies have noted the poor relationship between Al and Fe in soil (Freeland and Evans 1993), and soil solution (McDowell and Wood 1984). The apparently ambiguous trends in Fe release in this investigation can be elucidated by examining the ratio of Fe to DOC, as suggested by previous investigations of podzolization processes (Ugolini et al. 1991; McKeague et al. 1983). When the metal:organic carbon ratio in solution is low, the organo-metallic complex remains soluble and mobile. If metal:organic carbon ratios are sufficiently low, the organo-metallic complex may remove additional metals from primary minerals. In the soil profile, the complex is precipitated or adsorbed in the B horizon upon reaching a critical threshold (Buurman 1985; Ugolini et al. 1991) where the precipitated complex can continue to adsorb additional Fe (and Al) until the charge is neutralized (McKeague et al. 1983). Results of this investigation, which show Fe retention with FF-low and FF-medium treatments and release of Fe with FF-high (Figure 1-4), are in agreement with these previous investigations of podzolization which show a net retention of Fe in soil B horizons and suggest that this retention may be driven by Fe:organic ratios. To gain a better understanding of the release and retention of metals in combination with DOC, the chemistry of the soil as well as the solution must be examined. The influence of DOC on the quantity and chemical composition of grain coatings during this investigation has also been examined (Chapter 2).

The inorganic sol model of podzolization proposes that Al and Si are illuviated as a soluble aluminum silicate complex, $Al_2O_3$ - $SiO_2$ - $H_2O$. The presence of imogolite ($Si_2Al_4O_{10}$ * $5H_2O$) in the B horizons of podzolized soils is widely noted, yet there is great controversy as to whether imogolite is actually illuviated, or whether it forms <u>in situ</u> (Buurman and Van Reeuwijk 1984; Farmer 1984; Ugolini and Dahlgren 1991). The 2:1 ratio of Al:Si release in my data (Figure 1-2; Table 1-4) supports the hypothesis that Al and Si may be illuviated as imogolite or an imogolite-type material. My data do not rule out the possibility that Al may be transported via chelation when DOC levels are high. Although the inorganic sol model proposes that Al and Fe may be transported without the aid of an organic chelate, the model does not exclude the possibility that the organic chelate model is a feasible mechanism. In fact, metal-organic complexes appear to be more stable than inorganic sols, suggesting that formation and stability of inorganic sols may be a function of DOC concentration (Farmer et al. 1980; Wang et al. 1986). High concentrations of DOC may facilitate complexation of organic compounds with Al and Fe, thereby preventing formation of inorganic sols (Farmer et al. 1980). Previous investigations concluded that DOC concentration or soil organic matter content appears to have a significant role in determining whether the organic chelate model or the inorganic sol model is dominant (Wang et al. 1986). My results show consistently higher Al:Si molar ratios for the FF-medium and FF-high treatment than for the FF-low treatments. All of the FF-low treatments had Al:Si ratios below 1.5, whereas the FF-medium and FF-high treatments had Al:Si ratios closer to 2 or more (Table 1-4). Without separation of Al in solution into organic and inorganic fractions, it can not be determined whether Al is moving with DOC or in an inorganic form. However, the very strong relationship between release of Al and Si in a 2:1 Al:Si molar ratio suggests that Al and Si may be illuviated as imogolite during early stages of weathering.

Table 1-1. Selected characteristics of the four parent materials collected in New Hampshire.

| SERIES | CLASSIFICATION | SAMPLING LOCATION | SAMPLE DEPTH (m) | BEDROCK GEOLOGY | PARENT MATERIAL | DOMINANT MINERALS† | chemical composition‡ $SiO_2$ | $Al_2O_3$ | $CaO$ | $MgO$ | $Fe_2O_3$ | surface area# |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | weight percent of dry soil | | | | | $m^2$/gram |
| Hermon | Sandy-skeletal, mixed, frigid Typic Haplorthods | North Conway, NH | 1.0 | Conway Granite | glacial till rich in granite, gneiss | quartz, albite, biotite orthoclase, plagioclase | 71.4 | 13.7 | 0.58 | 0.28 | 2.68 | 2.135 |
| Marlow | Coarse-loamy, mixed, frigid Typic Haplorthods | West Thornton, NH | 1.4 | Kinsman Quartz Monzonite | glacial till rich in mica schist, granite | quartz, plagioclase, albite, phlogopite, muscovite | 71.9 | 13.9 | 1.54 | 0.65 | 2.42 | 2.725 |
| Success | Sandy-skeletal, mixed, frigid, ortstein Typic Haplorthods | Berlin, NH | 1.3 | Ammonoosuc Volcanics | glacial till rich in granite, gneiss | quartz, albite, biotite, muscovite, plagioclase | 69.2 | 14.6 | 1.49 | 0.76 | 2.41 | 1.002 |
| Lombard | Coarse-loamy, mixed, frigid Typic Haplorthods | Colebrook, NH | 1.1 | Frontenac (formerly Waits River) | saprolite rich in phyllite with inclusions of schist micaceous quartzite and carbonates†† | quartz, phlogopite, albite, muscovite | 69.5 | 13.1 | 1.95 | 2.06 | 4.01 | 6.071 |

† mineralogy determined by XRD

‡ chemical composition values are means of three replicates

# surface area values are from one BET measurement

†† additional information about composition from Hatch (1963).

Table 1- 2. Particle size distribution of the 0.053 - 11.2 mm size fraction of the soil materials. The less than 0.053 mm fraction was removed to prevent filter clogging. Size fractions were separated by dry sieving.

| | HERMON | MARLOW | SUCCESS | LOMBARD |
|---|---|---|---|---|
| | data in percent | | | |
| pebbles<br>4.0 - 11.2 mm | 32.4 | 13.7 | 16.1 | 12.1 |
| granules<br>2.0 - 4.0 mm | 25.1 | 9.4 | 7.0 | 17.4 |
| v. coarse sand<br>1.0 - 2.0 mm | 21.5 | 7.1 | 14.1 | 23.4 |
| coarse sand<br>0.5 - 1.0 mm | 11.6 | 12.9 | 21.8 | 15.4 |
| medium sand<br>0.25 - 0.5 mm | 6.1 | 15.8 | 19.7 | 8.9 |
| fine sand<br>0.125 - 0.25 mm | 2.3 | 14.7 | 12.3 | 8.9 |
| v. fine sand<br>0.053 - 0.125 mm | 0.9 | 26.5 | 9.1 | 13.8 |

Table 1-3. Concentration of DOC in the FF high treatment input solutions. The concentration of DOC FF-medium and FF-low treatments were 50% and 10% of the DOC concentration of the FF-high solution, respectively.

| event number | number of additions | mean | s. d. |
|---|---|---|---|
| | | mmol C/L | |
| 1 | 23 | 12.1 | 2.7 |
| 2 | 32 | 29.4 | 8.1 |
| 3 | 21 | 43.6 | 13.3 |
| 4 | 19 | 21.0 | 13.1 |
| 5 | 24 | 25.9 | 5.3 |

Table 1-4. Molar ratios of cumulative net Al and Si release (Al:Si) from soil materials to solution during the one year column leaching experiment. For all treatments, n = 3.

| | Hermon | Marlow | Success | Lombard |
|---|---|---|---|---|
| DW | 0.00 | 0.21 | 0.12 | 0.00 |
| $HNO_3$ | 4.72 | 4.09 | 3.32 | 0.13 |
| LOW | 1.23 | 1.20 | 1.46 | -0.01 |
| MED | 1.91 | 2.00 | 2.39 | 0.68 |
| HIGH | 2.38 | 1.86 | 2.29 | 0.68 |

Table 1-5. Percent element mobility (net moles released/moles in parent material * 100) for each parent material-solution treatment combination. For all treatments, n = 3.

| PM | treatment | Si | Al | Fe | Ca | Mg |
|---|---|---|---|---|---|---|
| Hermon | DW | 0.003 | 0.000 | -0.001 | 0.104 | 0.048 |
| | HNO3 | 0.014 | 0.292 | 0.006 | 0.633 | 0.050 |
| | LOW | 0.007 | 0.037 | -0.038 | 0.713 | 0.309 |
| | MEDIUM | 0.022 | 0.187 | -0.070 | 1.220 | 0.288 |
| | HIGH | 0.033 | 0.325 | 0.108 | 1.755 | 0.572 |
| Marlow | DW | 0.004 | 0.004 | 0.002 | 0.035 | 0.019 |
| | HNO3 | 0.031 | 0.555 | 0.007 | 1.551 | 0.059 |
| | LOW | 0.008 | 0.041 | -0.054 | 0.215 | 0.115 |
| | MEDIUM | 0.028 | 0.247 | -0.205 | 0.488 | 0.147 |
| | HIGH | 0.049 | 0.398 | -0.225 | 1.005 | 0.478 |
| Success | DW | 0.004 | 0.002 | -0.001 | 0.035 | 0.011 |
| | HNO3 | 0.032 | 0.427 | 0.006 | 1.044 | 0.057 |
| | LOW | 0.007 | 0.042 | -0.043 | 0.277 | 0.119 |
| | MEDIUM | 0.016 | 0.155 | -0.161 | 0.278 | 0.074 |
| | HIGH | 0.040 | 0.365 | 0.053 | 0.791 | 0.282 |
| Lombard | DW | 0.009 | 0.000 | 0.001 | 0.054 | 0.009 |
| | HNO3 | 0.043 | 0.026 | 0.001 | 5.222 | 1.245 |
| | LOW | 0.013 | -0.005 | -0.013 | 1.161 | 0.243 |
| | MEDIUM | 0.028 | 0.050 | 0.021 | 3.027 | 0.584 |
| | HIGH | 0.048 | 0.148 | 0.464 | 3.858 | 0.746 |

Table 1-6. Element mobility series for solution/parent material treatment based on rankings of percent element mobility data.

| Treatments grouped by parent material | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | least mobile | | | | | | | | most mobile |
| HERMON | Fe | < | Si | < | Al | < | Mg | < | Ca |
| MARLOW | Fe | < | Si | < | Al | < | Mg | < | Ca |
| SUCCESS | Fe | < | Si | < | Al | < | Mg | < | Ca |
| LOMBARD | Fe | < | Al | < | Si | < | Mg | < | Ca |
| **Treatments grouped by leaching solution** | | | | | | | | | |
| | least mobile | | | | | | | | most mobile |
| DISTILLED WATER | Fe | < | Al | < | Si | < | Mg | < | Ca |
| NITRIC ACID | Fe | < | Si | < | Al | = | Mg | < | Ca |
| FF-LOW | Fe | < | Si | < | Al | < | Mg | < | Ca |
| FF-MEDIUM | Fe | < | Si | < | Al | < | Mg | < | Ca |
| FF-HIGH | Si | < | Fe | < | Al | < | Mg | < | Ca |

Table 1-7. Mean pH of input and outflow solutions. For all samples, n = 45.

| | Input | Hermon | Marlow | Success | Lombard |
|---|---|---|---|---|---|
| DW | 5.6 | 5.8 | 5.6 | 5.8 | 6.3 |
| $HNO_3$ | 3.0 | 3.0 | 3.5 | 3.2 | 3.6 |
| FF LOW | 4.6 | 4.7 | 4.9 | 4.9 | 5.2 |
| FF MED | 4.2 | 4.4 | 4.7 | 4.6 | 4.9 |
| FF HIGH | 4.1 | 4.3 | 4.6 | 4.5 | 4.8 |

Table 1-8. Slope (m), intercept (b), regression coefficients ($r^2$), and p values for relationships between net element release and parent material chemical composition. For all regressions, n = 4.

| element | solution | Chemical composition m | b | $r^2$ | p value |
|---|---|---|---|---|---|
| Al | DW | 0.04 | -0.52 | 0.25 | 0.50 |
| | $HNO_3$ | 7.96 | -101 | 0.61 | 0.22 |
| | LOW | 0.85 | -11.0 | 0.74 | 0.14 |
| | MED | 2.08 | -24.4 | 0.32 | 0.44 |
| | HIGH | 4.41 | -52.5 | 0.71 | 0.16 |
| Si | DW | -0.11 | 8.65 | 0.21 | 0.55 |
| | $HNO_3$ | -0.56 | 42.9 | 0.31 | 0.44 |
| | LOW | -0.11 | 8.97 | 0.18 | 0.57 |
| | MED | 0.27 | -16.0 | 0.27 | 0.48 |
| | HIGH | 0.18 | 3.71 | 0.00 | 0.97 |
| Fe | DW | 0.00 | -0.01 | 0.23 | 0.52 |
| | $HNO_3$ | -0.01 | 0.04 | 0.95 | 0.03 |
| | LOW | 0.05 | -0.26 | 0.87 | 0.07 |
| | MED | 0.39 | -1.42 | 0.87 | 0.07 |
| | HIGH | 0.16 | -4.04 | 0.92 | 0.04 |
| Ca | DW | 0.04 | 0.06 | 0.32 | 0.43 |
| | $HNO_3$ | 10.6 | -8.27 | 0.59 | 0.23 |
| | LOW | 1.85 | -1.05 | 0.40 | 0.37 |
| | MED | 5.21 | -3.77 | 0.40 | 0.37 |
| | HIGH | 6.75 | -4.35 | 0.47 | 0.62 |
| Mg | DW | 0.01 | 0.02 | 0.52 | 0.28 |
| | $HNO_3$ | 3.91 | -2.02 | 0.94 | 0.03 |
| | LOW | 0.64 | -0.13 | 0.93 | 0.04 |
| | MED | 1.73 | -0.73 | 0.92 | 0.04 |
| | HIGH | 2.04 | -0.54 | 0.95 | 0.02 |

Release of Si and Al

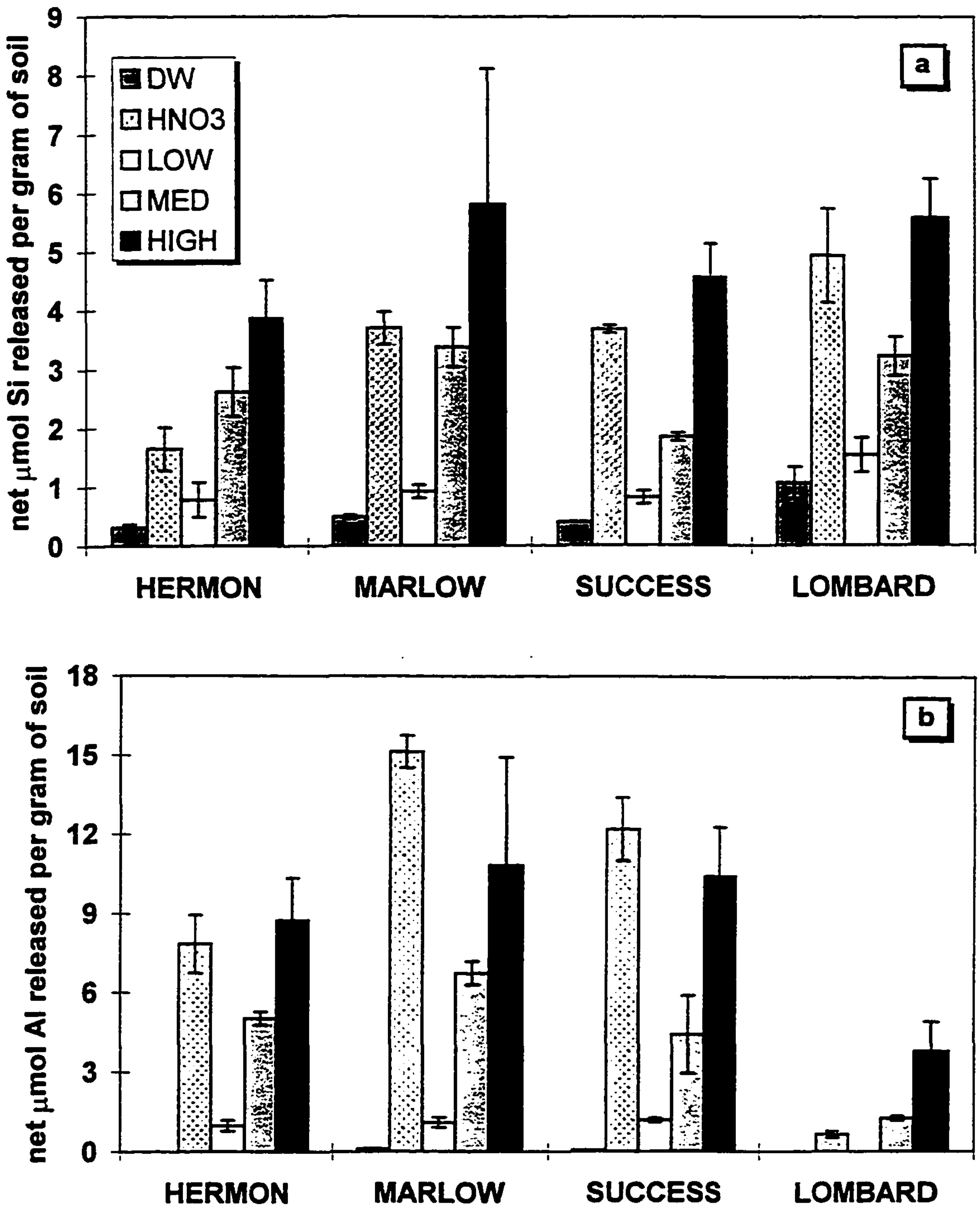



Figure 1-1. Net release of Si (graph a), and Al (graph b) during the one-year weathering period. The error bars are for one standard deviation. For all samples, n = 3.

Relationship between Al and Si release

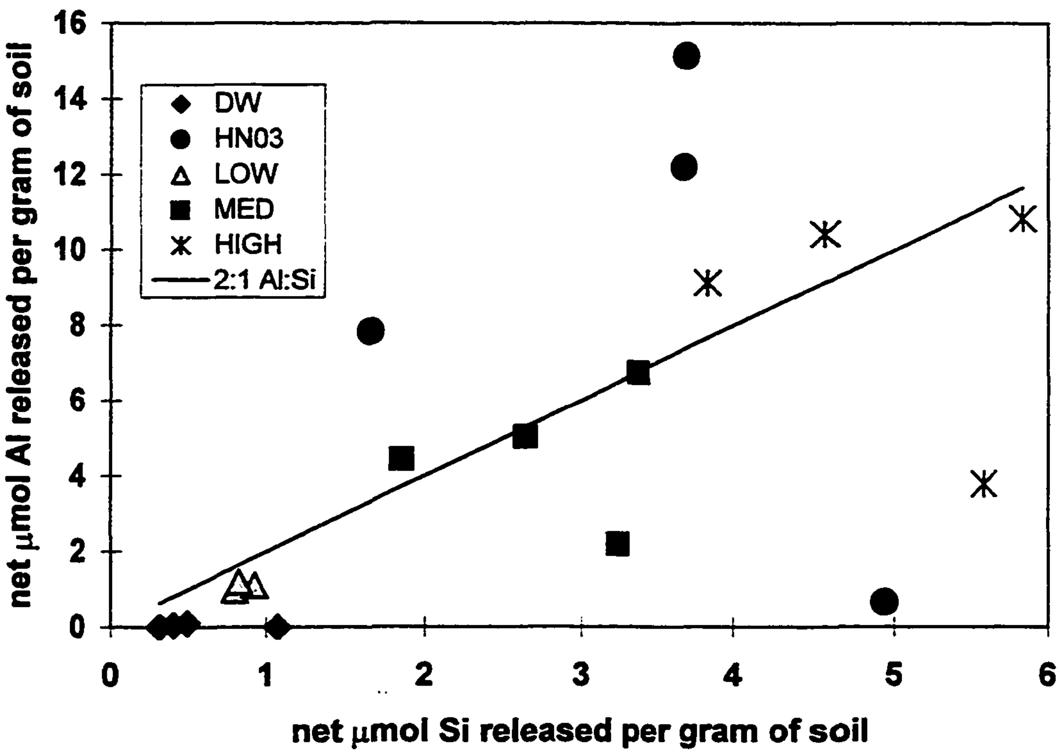



Figure 1-2. Relationship between net release of Si and Al per gram of soil ($r = 0.62$) for all treatments. When only the distilled water and forest floor leachate treatments are considered, the relationship is improved ($r = 0.83$). The line shown is the 2:1 line for Al:Si release, not a best fit to the data points.

Release of Mg and Ca

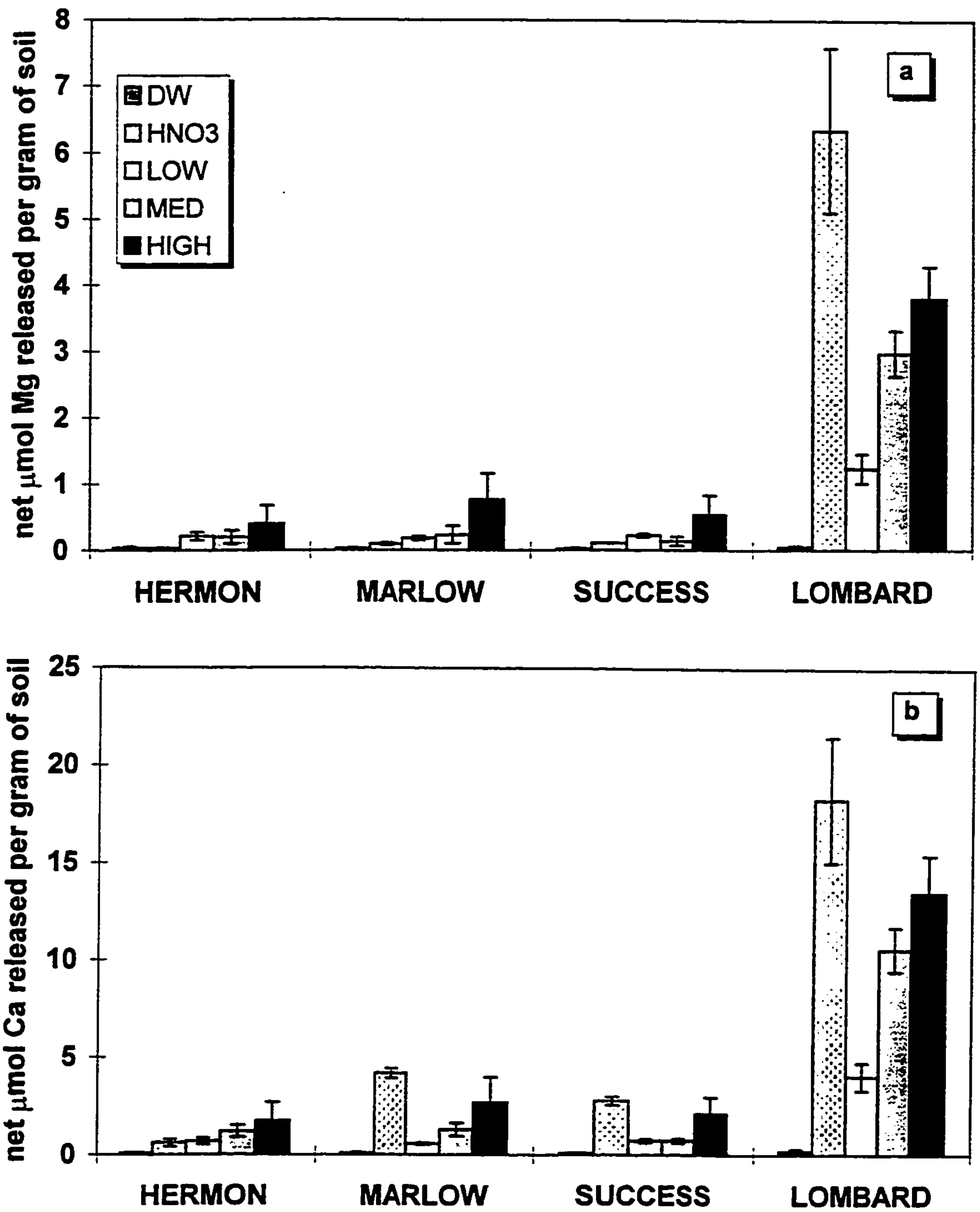



Figure 1-3. Net release of a) Mg, and b) Ca during the one-year weathering period. The error bars are for one standard deviation. For all samples, n = 3.

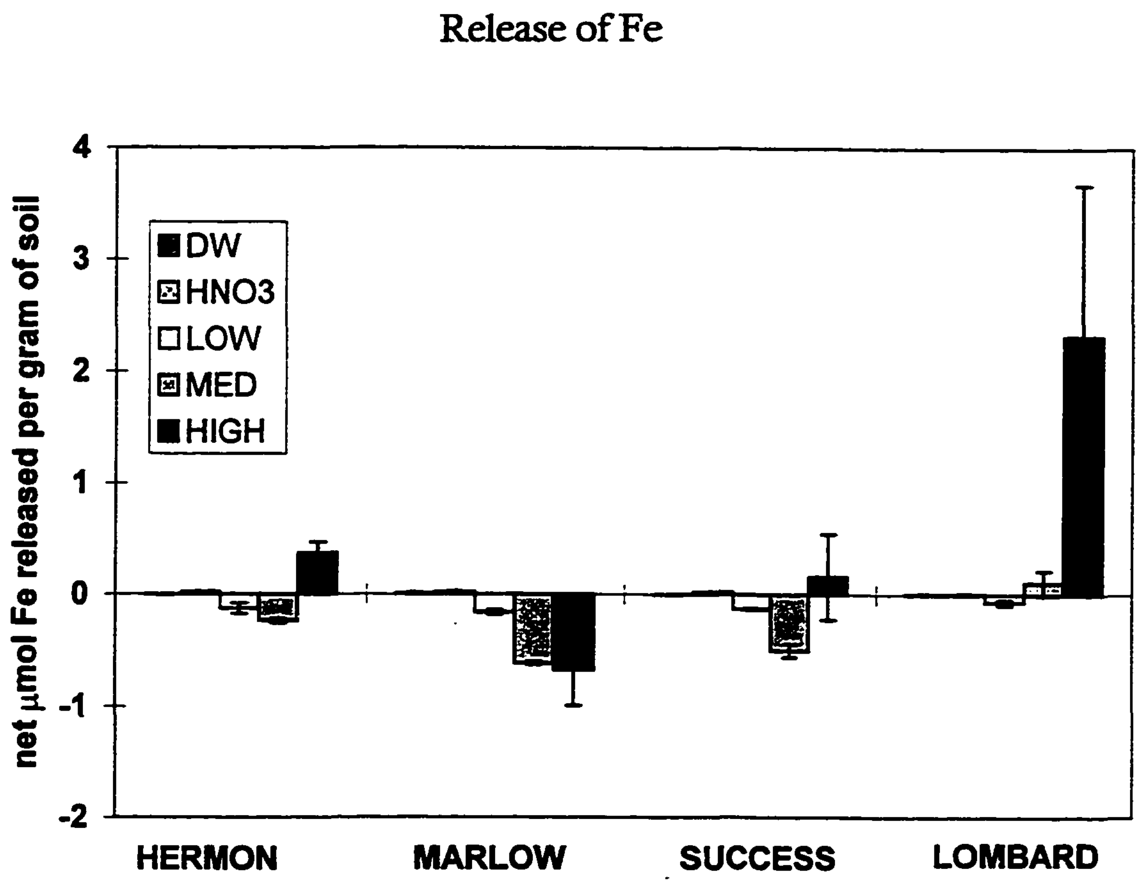
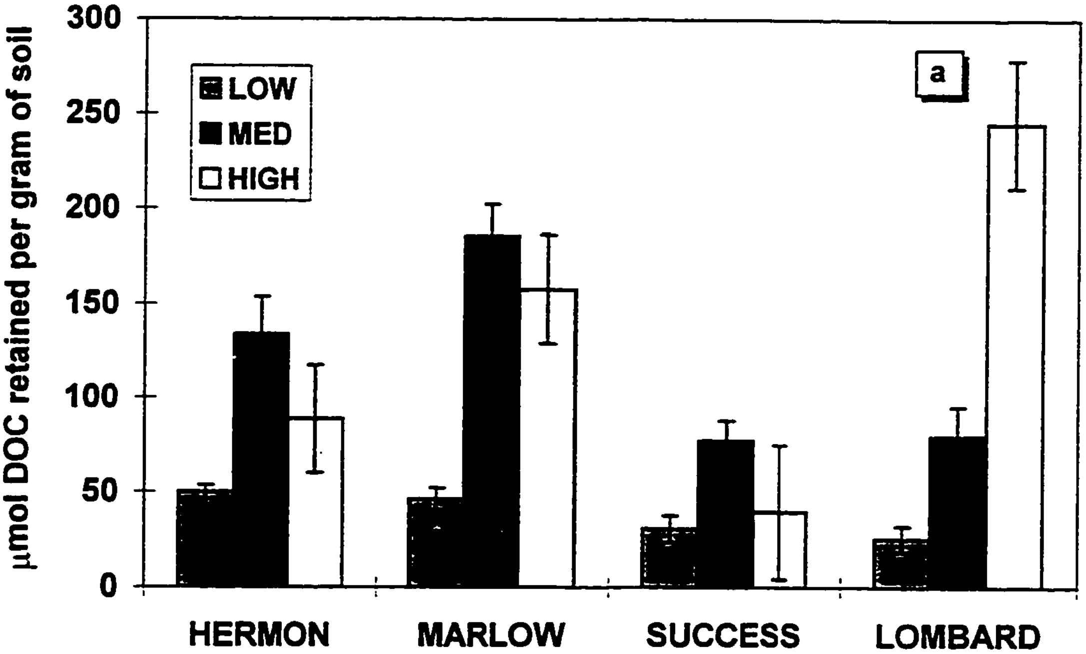



Figure 1-4. Net release of Fe during the one-year weathering period. The error bars are for one standard deviation. For all samples, n = 3.

DOC retention



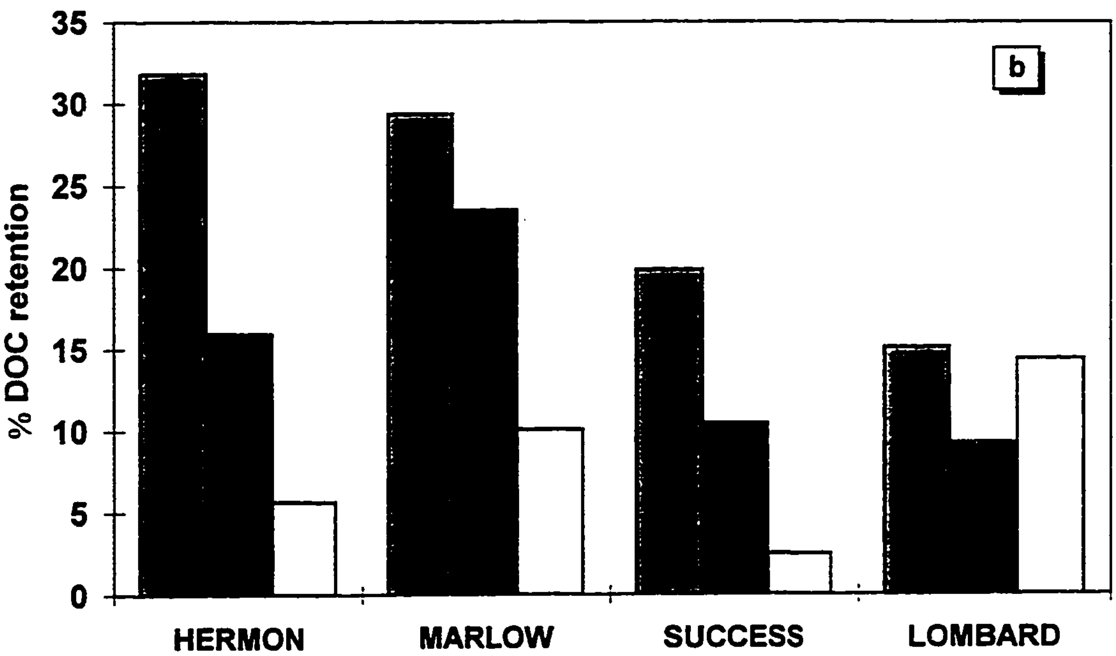




Figure 1-5. DOC retention, (a) net retention and (b) percent retention, during the investigation. The error bars on graph a are for one standard deviation. For all samples, n = 3.

## Relationships between pH and Al release

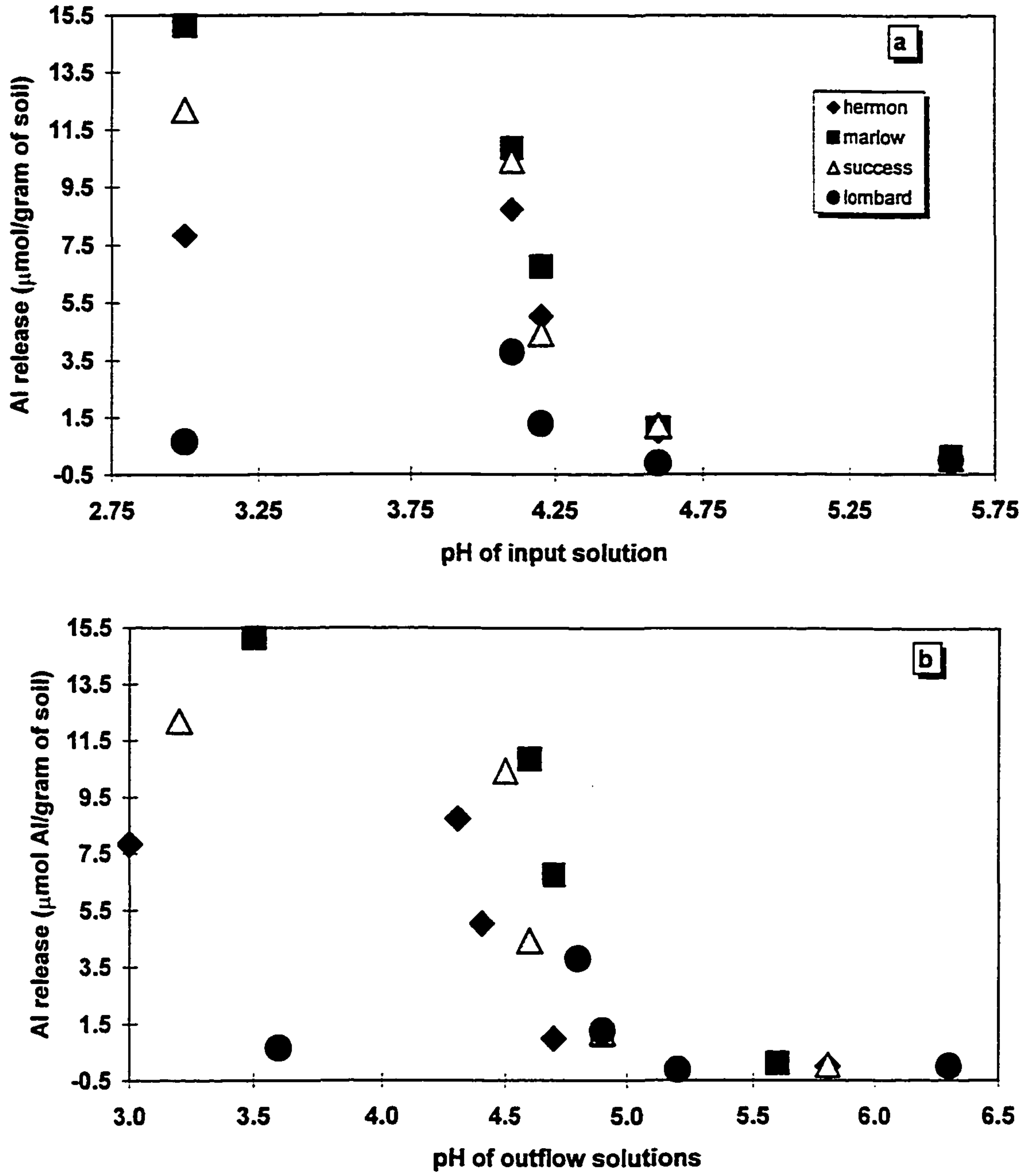



Figure 1-6. Relationships between Al release and (a) pH of the input solutions ($r^2 = 0.47$) and (b) pH of outflow solutions ($r^2 = 0.48$). Both relationships were greatly improved by excluding the Lombard parent material which contained a small amount of carbonate minerals (pH input vs. Al release $r^2 = 0.72$; pH outflow vs. Al release $r^2 = 0.61$). For graph a, the initial pH of the solution treatments are 5.6, 3.0, 4.6, 4.2 and 4.1 for the DW, nitric acid, FF-low, FF-medium and FF-high treatments, respectively.

## CHAPTER II.

# EFFECTS OF DOC CONCENTRATION ON ABUNDANCE AND CHEMICAL COMPOSITION OF GRAIN COATINGS

### Introduction

DOC entering mineral soil may be utilized by microbes, adsorbed onto soil surfaces or exported into surface or groundwaters (Cronan and Aiken 1985; McDowell and Likens 1988; Qualls et al. 1991). In most soils, the concentration of DOC declines with depth in the soil profile (Cronan and Aiken 1985; McDowell and Likens 1988; Guggenberger and Zech 1993). This reduction in DOC concentration has largely been attributed to abiotic retention by mineral soils with microbial degradation playing a secondary role (McDowell and Likens 1988; Qualls and Haines 1992). Much of this information has been determined primarily through study of soil solution chemistry. Examination of the changes in soil chemical properties and accumulation of grain coatings, coupled with solution chemistry would provide additional evidence to determine the relative importance of microbial utilization and abiotic sorption of DOC.

Objectives of this study were to: 1) Assess the relationship between DOC concentration in leaching solutions and changes in soil chemical properties; 2) Quantify changes in grain coatings following one year of leaching; and 3) Examine relationships between soil properties and solution chemistry. Additional goals of the study were to minimize differences between laboratory and field investigations by using natural heterogeneous solutions and soils. Several investigators have stressed the need for better alignment of laboratory studies with those of field conditions (Davis 1982; Casey et al. 1993; Santore et al. 1995; Courchesne et al 1996). Minimizing differences between laboratory and field investigations of soil formation will allow for an improved application of laboratory results to field settings and therefore a better understanding of pedogenesis and nutrient cycling.

## Materials and Methods

### Soil Characteristics

Parent materials from four Spodosol series in New Hampshire were selected for their range in soil chemical and physical properties. The Hermon, Marlow and Success parent materials were from profile C horizons. The Lombard parent material was collected from the IICr horizon of a road-cut. Mineralogy and chemical composition of the parent materials were determined using X-ray diffraction (Siemens Kristalloflex Diffraktometer D5000) and X-ray fluorescence spectroscopy (XRAL Activation Services Inc., Ann Arbor, MI). BET soil surface area was determined using a krypton adsorbate (Micromeritics Instrument Corp., Norcross, GA). Selected characteristics of the parent materials are found in Tables 2-1, 2-2 and Appendix A. The mineralogies of the four parent materials were similar, with quartz, feldspar and micaceous minerals dominating the composition. Unlike the three other parent materials, the Lombard material contains a small amount of carbonate minerals (Table 2-1) (Hatch 1963). The Lombard is derived from phyllite that ranges from easy to moderately-difficult to crush by hand. Due to the fragile nature of the Lombard material, measurements of surface area and particle size distribution of this material are only approximate measures. All materials had greater than 10 percent pebbles (4 - 11.2 mm) (Table 2-2). The Marlow parent material has the highest content of finer grains, and the Hermon material is the coarsest of the four soil materials. All samples have similar $Al_2O_3$ and $SiO_2$ content (Table 2-2). Chemical and physical variations among the parent materials include surface area and the content of $Fe_2O_3$, CaO, and MgO.

### Dissolved Organic Carbon Solution

Coniferous forest floor material collected in Durham, NH was refrigerated until used to make leachate solution. Forest floor leachate for each solution addition was freshly made by placing 840g of forest floor in 4.2 L of distilled water for six days. The solution was filtered (38 μm nylon filter, 0.45 μm cellulose nitrate filter) prior to application. Three concentrations of forest floor extract were used: FF-high (full strength), FF-medium (1:1 forest floor leachate to distilled water) and FF-low (1:9 forest floor leachate to distilled water). A sample of each input solution was saved to determine the concentration of DOC, Si and metals. The mean concentrations of DOC in the FF-high, FF-medium and FF-low input solutions were 26.5, 13.3 and 2.7 mmol C/L, respectively. The average pH values of the input solutions were FF-low = 4.6; FF-medium = 4.2; and FF- high = 4.1. Mean concentrations (μmol/L) of cations in the FF-high solution were: Al, 103; Ca, 236; Fe, 50.5; Mg, 74.7; and Si, 151. Additional details concerning the input solution chemistry are available in Chapter 1 and Appendix A.

Experimental Procedure

One hundred and ninety grams (mean soil depth = 32 mm) of air dried soil (0.053 - 11.2 mm) was packed into a Falcon Bottle Top Filter unit with a 38μm nylon filter in the bottom outlet (Figure 2-1). Column packing and sieving have been shown to cause only minimal disturbance in laboratory column weathering studies (Van Grinsven and Van Riemsdijk 1992). Effects of five solution treatments were evaluated – distilled water, 0.001 N nitric acid and three concentrations of forest floor leachate (FF-low, FF-medium, and FF-high). Triplicate columns of each parent material were prepared for each solution treatment for a total of 60 columns. Packed columns received 100 mL of solution (equivalent to 34 mm) every third day for 1 year. The cumulative solution addition during the study period was 4000 mm. The chemical composition of the solutions was analyzed both before and after percolation through the column to assess the net release of DOC, Si, Al, and Fe. Samples for DOC analysis were frozen; samples for analysis of other constituents were refrigerated at 4 $\pm$ 2 C. The organic carbon content of leachate solutions were determined using a Shimadzu TOC 5000 Total Organic Carbon Analyzer (high temperature Pt-catalyzed combustion). Total Al, Fe, and Si in solution and extracts were determined using a Beckman Direct Current Plasma Emission Spectroscopy (DCP). Additional details of experimental procedure and solution chemistry are available in Chapter 1 and Appendix A.

Following the one-year leaching treatments, soil pH (1:10 soil : water), % organic carbon, and % loss-on-ignition (LOI) were determined for samples from each treatment, and from untreated parent materials. Ammonium oxalate and sodium pyrophosphate extractable Al, Fe and Si were determined following the methods of Ross and Wang (1993). The extractable Al, Fe and Si from ammonium oxalate ($Al_o$, $Fe_o$ and $Si_o$) and sodium pyrophosphate ($Al_p$, $Fe_p$ and $Si_p$) are typically equated with total amorphous and organically complexed forms of these constituents, respectively. Additionally, the carbon content of the pyrophosphate extracts was measured to assess the % pyrophosphate extractable carbon ($C_p$). The carbon content of soil samples was determined using a Perkin Elmer CHN analyzer. Three thin-sections were made from one column of each parent material-solution treatment (Figure 2-1): profile cut (A), and two horizontal sections (B and C). Ten randomly selected locations were identified on each slide and 81 points on a grid were counted to determine the abundance of organo-metallic coatings (Galehouse 1971; Kelley 1971; Drees and Ransom 1994).

Differences among parent material/solution treatments were determined using ANOVA with Bonferroni multiple comparison test. A paired two-sample t-test was used to determine if solution and soil measures of OC accumulation were significantly different. Relationships among soil chemical and physical properties and between soil solution chemistry were assessed using Pearson's correlation. For all statistical analyses, statistical significance was established at $p \leq 0.05$.

## Results

### Soil Chemistry

Following one year of leaching, there were moderate reductions in the pH of the soils treated with FF leachates (Figure 2-2). The pH of the distilled water treated soils displayed a slight increase in pH, 0.1 to 0.4 pH units. Leaching with nitric acid decreased the pH by 0.3 to 0.4 units except for the Hermon soil where there was no significant change in pH. The Hermon, Marlow and Lombard soils showed a general trend of decreased pH with increased DOC concentration. All FF leachate treatments and nitric acid treatments resulted in a significant reduction ($p < 0.05$) in pH relative to the DW treatment of the same parent material, except for the Hermon parent material leached with the FF-low solution.

The soils leached with distilled water and nitric acid generally had a lower % LOI than the original parent material, although the differences were not statistically significant (Figure 2-3). Soil materials treated with FF-high leachate had higher % LOI values than the distilled water and nitric acid treatments. Only the Marlow parent material exhibited significant differences in % LOI among the FF leachate treatments ($p < 0.03$); the % LOI increased with increased DOC in the input solutions. Net % LOI was correlated with the net change in soil pH ($r = -0.56$; $p < 0.01$).

Quantities of ammonium-oxalate and sodium-pyrophosphate extractable Al, Fe and Si were low (0.5 %) in all samples following the year of solution treatment (Table 2-3). The ammonium oxalate extraction, removed significantly more Al, Fe and Si than the sodium pyrophosphate extraction for all samples ($p < 0.05$). Oxalate extractable quantities of Si ($Si_o$) or Al ($Al_o$) for the forest floor leachate treatments exhibited no clear trends, however there was a strong correlation between $Si_o$ and $Al_o$ ($r = 0.88$; $p < 0.01$). The pyrophosphate extractable Fe ($Fe_p$) and C ($C_p$) contents increased with increasing carbon input. The % $C_p$ for the FF-medium and FF-high treatments were significantly different ($p < 0.01$) than the distilled water treatment of the same parent material. The Marlow parent material treated with the FF-high solution had the highest % pyrophosphate extractable Al ($Al_p$), 0.36, which was significantly different from all other treatments ($p < 0.001$). Net % $Fe_p$, $C_p$ and $Al_p$, were all positively correlated with net % LOI ($r > 0.60$, $p < 0.005$). $Fe_p$ and $C_p$ had significant negative correlations with change in soil pH ($r < -0.64$; $p < 0.002$). There were high correlations between net (treatment - parent material) CHN-C and net % loss-on-ignition and $C_p$. The CHN values (Appendix A) must be interpreted with caution. The error associated with the CHN analyzer was $\pm$ 0.3 %, which is higher than almost all of the values reported. The values were included as a potential relative measure of % C between treatments. The high correlations between % CHN-C and % LOI and % $C_p$ support the use of the CHN data in this manner. Based upon correlation of CHN-C values and % loss-on-ignition, LOI in these samples is approximately 50% organic carbon. I will use this value here as it is in agreement with my pyrophosphate extractable C data as well as results from other investigations of the organic carbon content and loss-on-ignition values in podzolized sands and mineral soils (LOI as 38-55% organic carbon) (Goldin 1987; David 1988; Lowther et al. 1990). However, my CHN-C values should not be taken as an absolute measure of organic carbon in these samples.

Micromorphology

Examination of thin-sections from the columns allowed for comparison of accumulated organo-metallic coatings among solution treatments. In thin sections of the soil columns, organo-metallic coatings appeared as orange-brown to dark brown deposits on the edges of grains. There were visible differences among solution treatments. The distilled water and nitric acid treated soil materials had noticeably cleaner grains than the soils treated with FF leachate (Figure 2-4). The soils treated with FF-low leachate had occasional small pockets of light orange-brown coatings (Figure 2-5). The FF-medium and FF-high treatments had larger pockets of coatings as well as thin coatings surrounding entire grains. In the FF-high soils, the organo-metallic coatings were thicker and generally darker brown than the other treatments (Figure 2-6).

Thin sections from different areas of the columns (Figure 2-1 – A, B, and C) did not have significantly different quantities of grain coatings. Additionally, the location of the points on the profile view (thin section A for each column) had no distinguishable effect on the distribution of coatings. This homogeneity of the coating distribution is likely due to the slow percolation of the solution and thus the temporarily saturated conditions which it caused (maximum length of saturation was 24 hours in a 72 hour period). For these reasons, the three thin sections from each column treatment were treated as replicates. The distilled water and $HNO_3$ treatments both had a low net (treatment – original parent material) abundance of grain coatings (< 0.5 %) and were statistically indistinguishable. The abundance of organo-metallic coatings on grains increased with increasing concentration of DOC in the leachate solution (Figure 2-7). There were no significance differences among parent materials with the same solution treatment. The amount of grain coatings in FF-high treatments was significantly greater than in the distilled water, nitric acid and FF-low treatments for each parent material (p

< 0.01). Only the Lombard parent material FF-high treatment had a greater amount of coatings than the FF-medium treatment ($p < 0.001$). The net abundance of coatings was most strongly related to net % LOI and Cp (Figure 2-8). Abundance of coatings was also positively correlated with net % pyrophosphate Si ($Si_p$), $Fe_p$, and $Al_p$ ($r < 0.45$; $p < 0.047$) and negatively related to changes in soil pH ($r = -0.54$; $p < 0.01$).

Relationships between soil chemistry and solution chemistry

The net change in the solutions during percolation through the soil columns was reported in Chapter 1 and Appendix A. A summary table is given here (Table 2-4). With increased DOC input, net release of Si, Al, Ca and Mg to solution increased. Net removal of Fe and DOC from solution generally peaked at mid-level DOC concentrations. The amount of DOC retained by the soil materials had the strongest correlations with net % $Fe_p$ ($r = 0.73$; $p < 0.007$) and abundance of grain coatings ($r = 0.84$; $p < 0.001$) (Figure 2-9). The pattern of net Fe release to solution was correlated with $Fe_p$ ($r = 0.53$; $p < 0.02$). Net % LOI, CHN-C and $C_p$ were correlated with the DOC retention pattern ($r > 0.60$; $p < 0.03$) (Figure 2-10). Comparing the amount of DOC lost from solution (DOC retention) and the three measures of soil organic carbon accumulation (net $C_p$, CHN-C and 50 % LOI) used in this investigation, the soil measures of organic C accumulation are only 32 – 46 % of the amount of DOC lost from solution. Even if a higher value of organic carbon is assumed for loss on ignition (e.g. 55%) the amount of organic carbon accumulated on soil was only 50% of DOC retention as measured by solution chemistry.

## Discussion

Results of this investigation confirm that changes in soil chemical properties are the direct outcome of leaching by DOC-rich solutions. Soils treated with FF leachate treatments had lower soil pH values than soil leached with distilled water. This effect was anticipated due to the acidic nature of many of the components such as humic and fulvic acids. Typically, the acidity of dissolved organic compounds can be attributed to ionization of hydroxyl (OH) groups of carboxyls and phenols although other functional groups may be involved (Stevenson 1994). Many of the soils leached with FF solutions had lower pH values than soils leached with 0.001 N $HNO_3$. Results of this study clearly illustrate the importance of heterogeneous DOC in altering soil pH and accelerating natural soil forming processes. Investigations of podzolization and DOC dynamics have noted decreased DOC concentrations with depth in the soil profile (Cronan and Aiken 1985; McDowell and Likens 1988; Guggenberger and Zech 1993) as well as significant changes in soil chemical properties. Pedogenic processes clearly impact soil chemical properties, as illustrated by chemical changes of spodic horizons relative to the underlying parent materials. These changes include decreased soil pH and increased CEC as well as greater quantities of organic carbon and extractable Al, Fe, Si and C (Olsson and Melkerud 1989; Barrett and Schaetzl 1992; Kennedy et al. 1996).

Leaching with DOC, especially high concentrations, resulted in a significant gain in % LOI, %CHN-C and % pyrophosphate extractable carbon. Examination of the changes in soil solution chemistry indicates high net loss of DOC from solution during leaching. Results of this investigation suggest that abiotic retention of DOC may not have been the only factor involved in removing DOC from solution (Figure 2-10). The amount of OC accumulated on mineral soil surfaces, based upon % LOI (LOI = 50% OC, this investigation; Nelson and Sommers 1982; Goldin 1987; David 1988; Lowther et al. 1990), %Cp and % CHN-C, was well below (32 - 46%) the amount of OC retained based upon solution chemistry. However, it must be noted that due to the sampling scheme during the first few months of the column study, our final calculations of DOC loss from solution may be over-estimated by an average of 5 % (range = 4 to 6 %) based upon the slope of the linear regression line (See Appendix A for additional details). Even with the correction for the possible over-estimation of DOC retention on mineral soil, DOC retention based upon solution chemistry was much higher than the OC content measured via LOI, Cp and CHN-C (Appendix A). From my data, it is not possible to determine whether microbes utilized DOC in solution or if decomposition of sorbed DOC followed abiotic retention on mineral surfaces. This missing carbon may have been released as $CO_2$ or may have been leached as carbonic acid. In any case, there is a significant discrepancy between the amount of OC removed from solution and the amount of OC on soil surfaces, thus clearly indicating that examinations of soil organic carbon and DOC dynamics based entirely on solution chemistry are not a complete and accurate measure of C retention or storage capacity in mineral soils.

Previous shorter term investigations of DOC retention based on solution chemistry (McDowell and Wood 1984; Qualls and Haines 1992) indicate that abiotic retention is the major mechanism responsible for the decline in DOC concentrations in soil solution. The net loss of DOC from solution during percolation through the column (Table 2-4) coupled with the increase in organic carbon in the soil materials confirms the importance of abiotic sorption in controlling DOC concentrations, yet also suggests an important role for microbial utilization in longer-term experiments. Mayer (1994 a, b) noted a consistent relationship between surface area and organic carbon content in soils and sediments, termed the monolayer equivalent (0.86 mg OC per $m^2$). Following one year of leaching, the soil materials retained between 0.05 and 0.92 mg OC per $m^2$, based on soil solution data which assumes minimal microbial decomposition of DOC. The net accumulation of organic carbon based on soil chemistry was significantly lower (mean 0.2 mg OC per $m^2$; $p < 0.01$) than the estimates based on solution chemistry. There was also a marked increase in pyrophosphate extractable Fe in soils leached with DOC solutions. DOC and Fe in some FF leachate treatments exhibited a net retention pattern during solution percolation through the column. The strong correlations between the abundance of grain coatings, measures of DOC retention (solution chemistry, % LOI and % $C_p$) and $Fe_p$ support the hypothesis that the grain coatings are partially composed of organic carbon and Fe (Figures 2-7, 2-8, 2-9). This fast accumulation of organo-metallic grain coatings and changes in soil chemical properties support theories of rapid formation (< 10,000 years) for podzolized soils (McKeague et al. 1983; Birkeland 1989).

The distribution of Al, Fe and Si net release from soil parent materials is illustrated in Figures 2-11, 2-12 and 2-13. For the majority of the treatments, Al released to solution comprised less than 50% of the net change in the distribution of Al. Extractable Al was particularly important in the distilled water treatments and at lower levels of FF leachate. The low pH of the $HNO_3$ and FF high solutions may account for the increased amount of Al released to solution from these treatments. Examination of the change in distribution of Al in these materials illustrates the importance of solution chemistry as well as formation of Al-rich organic and inorganic coatings during soil formation. Accumulation of Si and Fe in secondary coatings comprised a much larger proportion of the change in the distribution of these elements than release to solution. Si release to solution during the one-year leaching period was low for all treatments (< 1.2 mmol per 190 grams of soil). The quantity of oxalate extractable Si was particularly large relative to Si release to solution. Pyrophosphate extractable Fe did tend to accumulate with increased DOC inputs, but overall, the change in Fe distribution did not have a clear trend with solution treatment. The accumulation of grain coatings is particularly important as they are typically much more chemically reactive than the primary minerals from which they originate (Bohn et al. 1985; Courchesne et al. 1996). Release of Al, Fe and Si to solution may only account for a small portion of the total change in the distribution of these elements during weathering. Results of this investigation indicate that the grain coatings formed during initial stages of weathering can be rich in Al, Fe, Si and organic C and are in agreement with previous examinations of the composition of grain coatings in podzolized soils (DeConinck 1980; Olsson and Melkerud 1989; Courchesne et al. 1996).

This investigation focused on changes in soil and solution chemistry during the initial stages of pedogenesis. This dual approach allows for a more complete understanding of the processes involved in soil formation than would either approach alone. Examination of the dynamics of DOC and soil organic carbon indicates that abiotic retention of DOC plays an important role in accumulation of organic carbon in soils, yet because of the high potential for microbial utilization of DOC and soil organic carbon, both solution and soil chemistry must be investigated. Additionally, changes in soil materials during weathering are complex because many inorganic constituents (e.g. Si, Fe and Al) may be released to solution and may also form secondary minerals or organo-metallic coatings (DeConinck 1980; Olsson and Melkerud 1989;

Courchesne et al. 1996). Therefore, as with organic carbon dynamics, both solution and soil chemistry must be examined to determine the distribution of element release to solution and formation of new solid phases.

Table 2-1. Selected characteristics of the parent materials.

| | HERMON | MARLOW | SUCCESS | LOMBARD |
|---|---|---|---|---|
| classification | Sandy-skeletal, mixed, frigid Typic Haplorthods | Coarse-loamy, mixed, frigid Typic Haplorthods | Sandy-skeletal, mixed, frigid, ortstein Typic Haplorthods | Coarse-loamy, mixed, frigid Typic Haplorthods |
| location | North Conway, NH | West Thorton, NH | Berlin, NH | Colebrook, NH |
| depth (meters) | 1.0 | 1.4 | 1.3 | 1.1 |
| bedrock geology | Conway Granite | Kinsman Quartz Monzonite | Ammonoosuc Volcanics | Frontenac (formerly Waits River) |
| parent material composition | glacial till rich in granite, gneiss | glacial till rich in mica schist, granite | glacial till rich in granite, gneiss | saprolite rich in phyllite with inclusions of schist micaceous quartzite and carbonates[††] |
| dominant minerals[†] | quartz, albite, biotite, orthoclase, plagioclase | quartz, plagioclase, albite, phlogopite, mucsovite | quartz, albite, biotite, muscovite, plagioclase | quartz, phlogopite, albite, muscovite |

[†] mineralogy determined by XRD

[††] additional information about composition from Hatch (1963).

Table 2-2. Chemical composition, surface area and particle size distribution of the 0.053 - 11.2 mm size size fraction of the soil materials. Particle size was determined by dry sieving. The < 0.053 mm fraction was removed to prevent filter clog.

| SERIES | chemical composition[†] $SiO_2$ | $Al_2O_3$ | CaO | MgO | $Fe_2O_3$ | surface area[††] | particle size distribution- millimeters 0.053-0.125 | 0.125-0.250 | 0.250-0.500 | 0.500-1.00 | 1.00-2.00 | 2.00-4.00 | 4.00-11.2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | weight percent of dry soil | | | | | $m^2$/gram | percent | | | | | | |
| Hermon | 71.4 | 13.7 | 0.58 | 0.28 | 2.68 | 2.13 | 0.9 | 2.3 | 6.1 | 11.6 | 21.5 | 25.1 | 32.4 |
| Marlow | 71.9 | 13.9 | 1.54 | 0.65 | 2.42 | 2.73 | 26.5 | 14.7 | 15.8 | 12.9 | 7.1 | 9.4 | 13.7 |
| Success | 69.2 | 14.6 | 1.49 | 0.76 | 2.41 | 1.00 | 9.1 | 12.3 | 19.7 | 21.8 | 14.1 | 7.0 | 16.1 |
| Lombard | 69.5 | 13.1 | 1.95 | 2.06 | 4.01 | 6.07 | 13.8 | 8.9 | 8.9 | 15.4 | 23.4 | 17.4 | 12.1 |

[†] chemical composition values are means of three replicates

[††] surface area values are from one BET measurement

TABLE 2-3. Mean values for ammonium oxalate and sodium pyrophosphate extractable Si, Al, Fe and C. Standard deviations are in italics. For all samples, n = 2.

| PARENT MATERIAL | SOLUTION TREATMENT | $Si_o$ | $Fe_o$ | $Al_o$ | $Si_p$ | $Fe_p$ | $Al_p$ | $C_p$ |
|---|---|---|---|---|---|---|---|---|
| | | | | | data in percent | | | |
| HERMON | PM | 0.05 | 0.14 | 0.12 | 0.02 | 0.03 | 0.05 | 0.03 |
| | | *<0.01* | *<0.01* | *<0.01* | *<0.01* | *0.01* | *<0.01* | *<0.01* |
| | DW | 0.09 | 0.23 | 0.16 | 0.02 | 0.04 | 0.06 | 0.05 |
| | | *<0.01* | *0.02* | *<0.01* | *<0.01* | *<0.01* | *<0.01* | *<0.01* |
| | $HNO_3$ | 0.07 | 0.28 | 0.12 | 0.02 | 0.03 | 0.05 | 0.05 |
| | | *<0.01* | *0.01* | *<0.01* | *<0.01* | *<0.01* | *<0.01* | *<0.01* |
| | FF LOW | 0.06 | 0.17 | 0.13 | 0.02 | 0.03 | 0.06 | 0.05 |
| | | *<0.01* | *<0.01* | *<0.01* | *<0.01* | *<0.01* | *<0.01* | *0.02* |
| | FF MED | 0.08 | 0.22 | 0.16 | 0.03 | 0.05 | 0.07 | 0.15 |
| | | *<0.01* | *<0.01* | *<0.01* | *<0.01* | *<0.01* | *<0.01* | *0.01* |
| | FF HIGH | 0.06 | 0.17 | 0.11 | 0.03 | 0.05 | 0.05 | 0.12 |
| | | *0.01* | *0.05* | *0.02* | *<0.01* | *<0.01* | *<0.01* | *<0.01* |
| MARLOW | PM | 0.06 | 0.08 | 0.17 | 0.02 | 0.03 | 0.08 | 0.06 |
| | | *0.01* | *<0.01* | *0.01* | *<0.01* | *<0.01* | *<0.01* | *<0.01* |
| | DW | 0.12 | 0.17 | 0.26 | 0.02 | 0.04 | 0.11 | 0.01 |
| | | *0.01* | *<0.01* | *<0.01* | *<0.01* | *<0.01* | *0.01* | *0.01* |
| | $HNO_3$ | 0.07 | 0.12 | 0.17 | 0.02 | 0.03 | 0.09 | 0.06 |
| | | *<0.01* | *<0.01* | *<0.01* | *<0.01* | *<0.01* | *<0.01* | *0.01* |
| | FF LOW | 0.09 | 0.14 | 0.21 | 0.02 | 0.03 | 0.10 | 0.07 |
| | | *<0.01* | *<0.01* | *<0.01* | *<0.01* | *<0.01* | *<0.01* | *<0.01* |
| | FF MED | 0.07 | 0.11 | 0.19 | 0.02 | 0.05 | 0.11 | 0.20 |
| | | *<0.01* | *<0.01* | *<0.01* | *<0.01* | *<0.01* | *<0.01* | *0.03* |
| | FF HIGH | 0.10 | 0.15 | 0.24 | 0.03 | 0.06 | 0.14 | 0.36 |
| | | *<0.01* | *<0.01* | *<0.01* | *<0.01* | *<0.01* | *<0.01* | *0.03* |
| SUCCESS | PM | 0.07 | 0.08 | 0.12 | 0.01 | 0.02 | 0.06 | 0.05 |
| | | *<0.01* | *<0.01* | *<0.01* | *<0.01* | *<0.01* | *<0.01* | *<0.01* |
| | DW | 0.06 | 0.07 | 0.14 | 0.02 | 0.03 | 0.07 | 0.03 |
| | | *<0.01* | *0.01* | *<0.01* | *<0.01* | *<0.01* | *<0.01* | *0.02* |
| | $HNO_3$ | 0.05 | 0.12 | 0.12 | 0.02 | 0.03 | 0.06 | 0.06 |
| | | *<0.01* | *0.01* | *<0.01* | *<0.01* | *<0.01* | *<0.01* | *0.01* |
| | FF LOW | 0.06 | 0.12 | 0.13 | 0.02 | 0.03 | 0.06 | 0.06 |
| | | *<0.01* | *0.01* | *0.01* | *<0.01* | *<0.01* | *<0.01* | *0.02* |
| | FF MED | 0.06 | 0.11 | 0.13 | 0.03 | 0.04 | 0.07 | 0.13 |
| | | *<0.01* | *0.01* | *<0.01* | *<0.01* | *<0.01* | *<0.01* | *0.01* |
| | FF HIGH | 0.06 | 0.11 | 0.13 | 0.03 | 0.04 | 0.07 | 0.19 |
| | | *<0.01* | *0.01* | *<0.01* | *<0.01* | *<0.01* | *<0.01* | *0.05* |
| LOMBARD | PM | 0.05 | 0.29 | 0.06 | 0.01 | 0.02 | 0.02 | 0.01 |
| | | *<0.01* | *0.01* | *<0.01* | *<0.01* | *<0.01* | *<0.01* | *<0.01* |
| | DW | 0.13 | 0.40 | 0.13 | 0.02 | 0.05 | 0.04 | 0.01 |
| | | *<0.01* | *0.01* | *<0.01* | *<0.01* | *0.01* | *<0.01* | *0.01* |
| | $HNO_3$ | 0.09 | 0.38 | 0.11 | 0.02 | 0.05 | 0.03 | 0.00 |
| | | *<0.01* | *0.03* | *0.01* | *<0.01* | *<0.01* | *<0.01* | *<0.01* |
| | FF LOW | 0.08 | 0.43 | 0.10 | 0.02 | 0.05 | 0.03 | 0.07 |
| | | *<0.01* | *0.01* | *<0.01* | *<0.01* | *<0.01* | *<0.01* | *<0.01* |
| | FF MED | 0.07 | 0.35 | 0.08 | 0.02 | 0.06 | 0.03 | 0.14 |
| | | *<0.01* | *0.01* | *<0.01* | *<0.01* | *<0.01* | *<0.01* | *<0.01* |
| | FF HIGH | 0.08 | 0.37 | 0.09 | 0.02 | 0.08 | 0.04 | 0.15 |
| | | *<0.01* | *0.01* | *<0.01* | *<0.01* | *0.01* | *<0.01* | *0.01* |

TABLE 2-4. Net cumulative release or retention of solution constituents from soil columns leached for one year. For solution retention and release samples, n = 3.

| PARENT MATERIAL | SOLUTION | C RETENTION | | Si RELEASE | | Al RELEASE | | Fe RELEASE | | SOLUTION pH |
|---|---|---|---|---|---|---|---|---|---|---|
| | | μmol C/gram soil | | ——— μmol released/gram soil ——— | | | | | | |
| | | mean | s.d.† | mean | s.d. | mean | s.d. | mean | s.d. | mean |
| HERMON | DW | n.d.‡ | n.d. | 0.32 | 0.05 | 0.00 | < 0.01 | 0.00 | 0.01 | 5.8 |
| | HNO3 | n.d. | n.d. | 1.66 | 0.37 | 7.84 | 1.10 | 0.02 | < 0.01 | 3.0 |
| | FF LOW | 49.7 | 3.58 | 0.79 | 0.30 | 0.99 | 0.20 | -0.13 | 0.04 | 4.7 |
| | FF MED | 134 | 19.8 | 2.63 | 0.41 | 5.03 | 0.25 | -0.24 | 0.02 | 4.4 |
| | FF HIGH | 88.7 | 28.6 | 3.87 | 0.65 | 8.74 | 1.62 | 0.37 | 0.10 | 4.3 |
| MARLOW | DW | n.d. | n.d. | 0.49 | 0.04 | 0.10 | 0.03 | 0.01 | 0.01 | 5.6 |
| | HNO3 | n.d. | n.d. | 3.70 | 0.28 | 15.1 | 0.62 | 0.02 | 0.01 | 3.5 |
| | FF LOW | 46.0 | 5.94 | 0.93 | 0.11 | 1.11 | 0.19 | -0.16 | 0.02 | 4.9 |
| | FF MED | 186 | 16.7 | 3.38 | 0.33 | 6.75 | 0.44 | -0.62 | 0.01 | 4.7 |
| | FF HIGH | 158 | 28.7 | 5.82 | 2.30 | 10.9 | 4.09 | -0.68 | 0.32 | 4.6 |
| SUCCESS | DW | n.d. | n.d. | 0.41 | < 0.01 | 0.05 | 0.01 | 0.00 | < 0.01 | 5.8 |
| | HNO3 | n.d. | n.d. | 3.68 | 0.06 | 12.2 | 1.20 | 0.02 | 0.01 | 3.2 |
| | FF LOW | 30.6 | 7.02 | 0.83 | 0.11 | 1.20 | 0.07 | -0.13 | < 0.01 | 4.9 |
| | FF MED | 77.2 | 10.9 | 1.86 | 0.06 | 4.43 | 1.47 | -0.48 | 0.06 | 4.6 |
| | FF HIGH | 39.7 | 35.4 | 4.57 | 0.58 | 10.4 | 1.86 | 0.16 | 0.39 | 4.5 |
| LOMBARD | DW | n.d. | n.d. | 1.07 | 0.28 | 0.00 | 0.01 | 0.01 | < 0.01 | 6.3 |
| | HNO3 | n.d. | n.d. | 4.94 | 0.81 | 0.66 | 0.12 | 0.00 | 0.01 | 3.6 |
| | FF LOW | 25.5 | 6.73 | 1.55 | 0.29 | -0.12 | 0.07 | -0.07 | 0.03 | 5.2 |
| | FF MED | 79.6 | 15.9 | 3.23 | 0.32 | 1.27 | 0.09 | 0.11 | 0.11 | 4.9 |
| | FF HIGH | 245 | 33.7 | 5.59 | 0.66 | 3.79 | 1.11 | 2.32 | 1.35 | 4.8 |

† s.d. = standard deviation

‡ n.d. = not determined

Column set-up

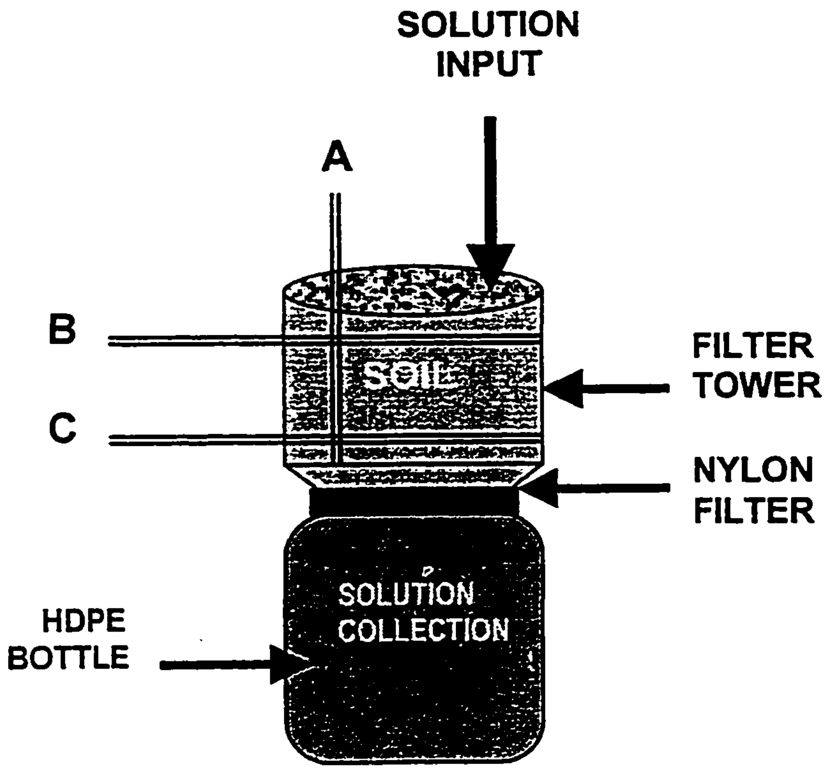



Figure 2-1. Schematic diagram of the columns used in this study. Solution was added to columns every third day for one year. Following the year of leaching, soil chemical properties and micromorphology were examined. Three thin-sections were made from one column of each soil-solution treatment: profile cut (A) and two cross-sections (B, C).

Chemical analysis: Soil pH

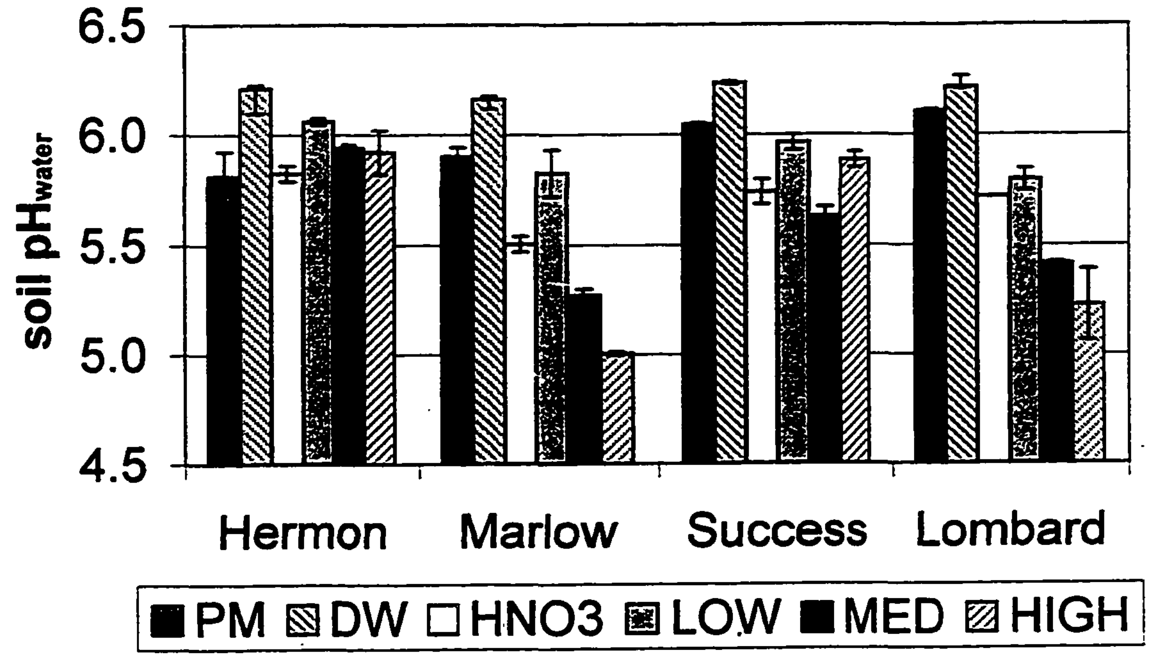



Figure 2-2. Soil pH (1:10, soil : water) following the one-year weathering period. PM is the original parent material. The error bars are for one standard deviation. For all samples, n = 2.

Chemical analysis: Percent loss-on-ignition

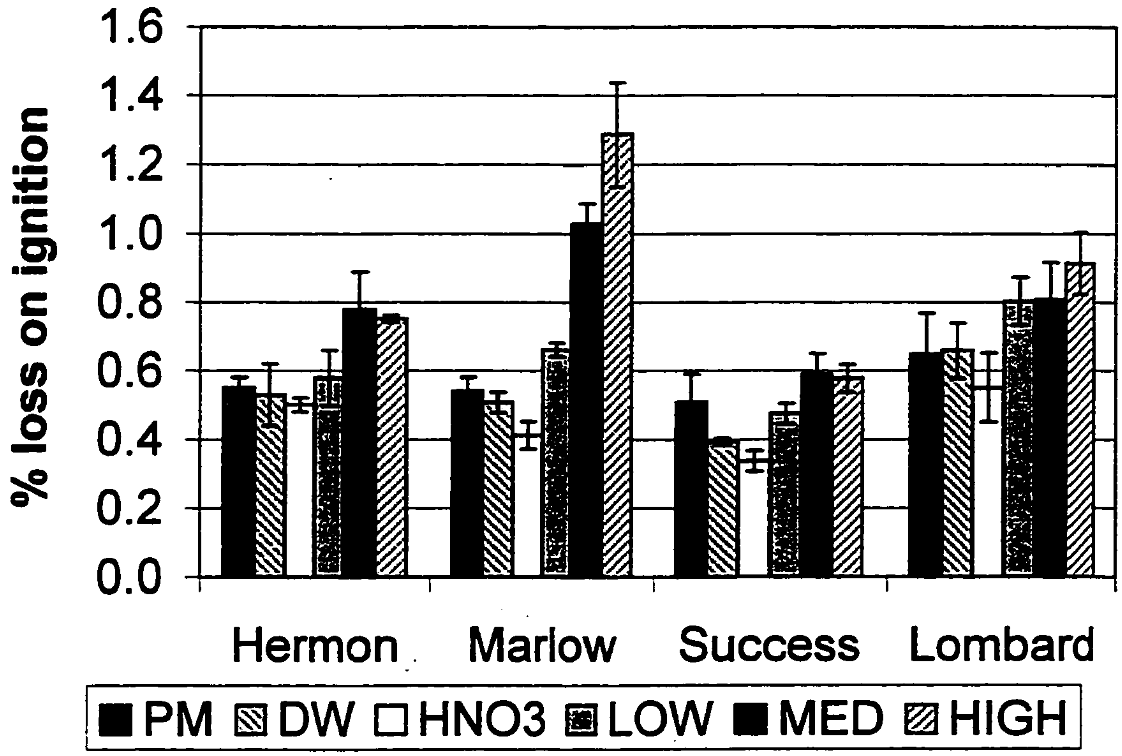



Figure 2-3. Percent loss on ignition following the one-year leaching experiment. PM is the original parent material. The error bars indicate one standard deviation. For all samples, n=3.

## Photomicrograph – Nitric acid treatment

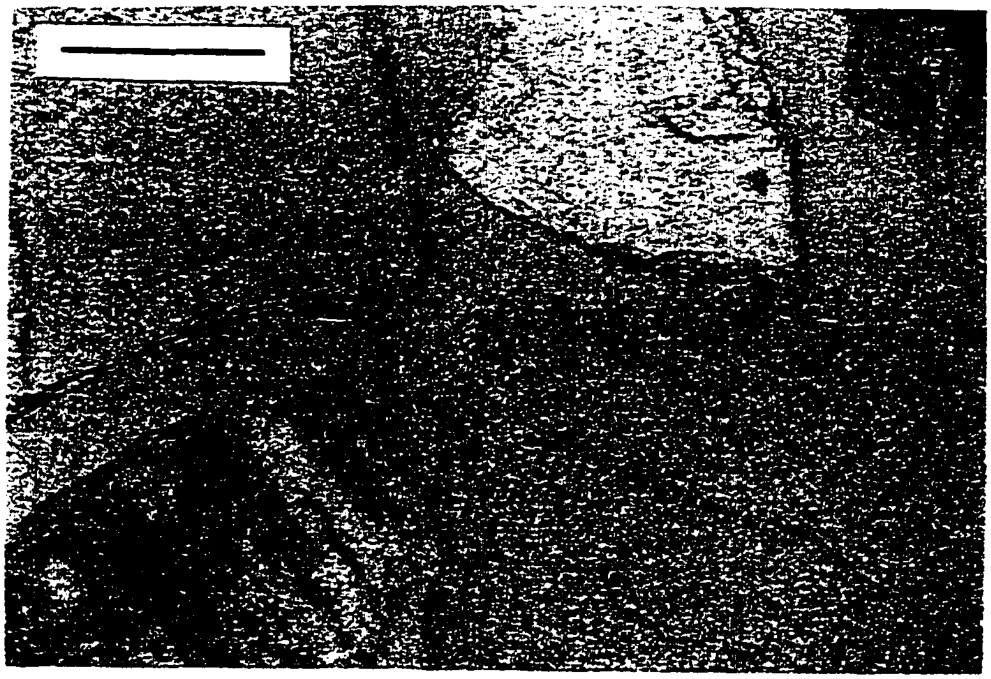


Figure 2-4. Examination of thin-sections allowed for comparison of accumulation of organo-metallic coatings among solution treatments. The photomicrograph above is of the Success parent material treated with nitric acid. The line on the top of the photo is 0.05 cm in length.

## Photomicrograph – Forest floor low treatment

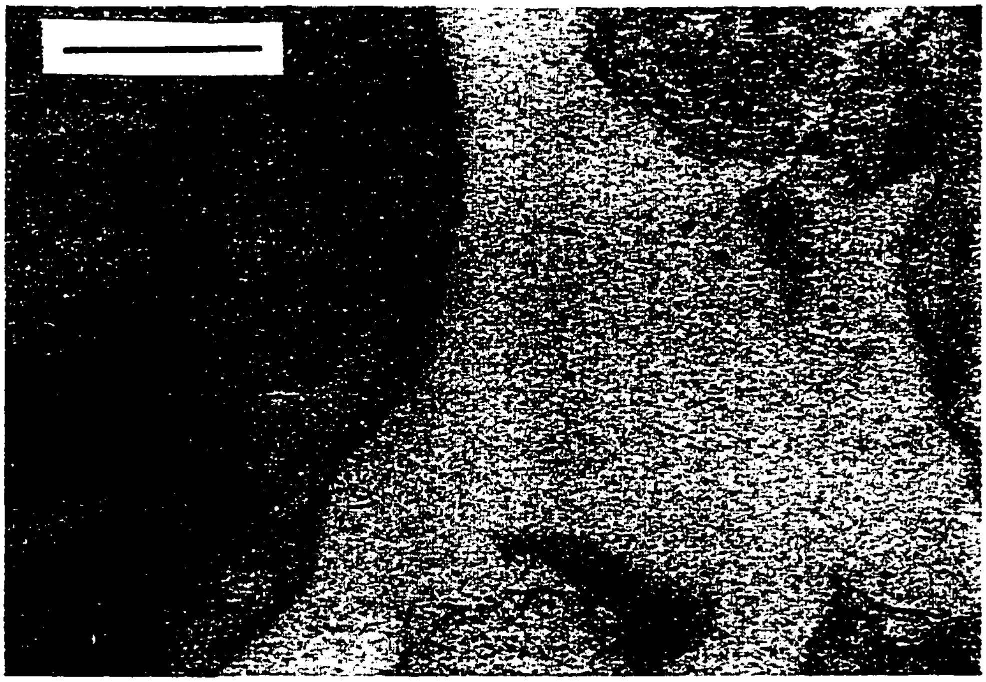


Figure 2-5. The photomicrograph above is of the Success parent material treated with the low concentration of forest floor leachate. The small line is 0.05 cm in length. The grains treated with nitric acid are noticeably cleaner than grains treated with forest floor low leachate which show accumulation of organic-metallic coatings in thin coatings.

Photomicrograph – Forest floor high treatment

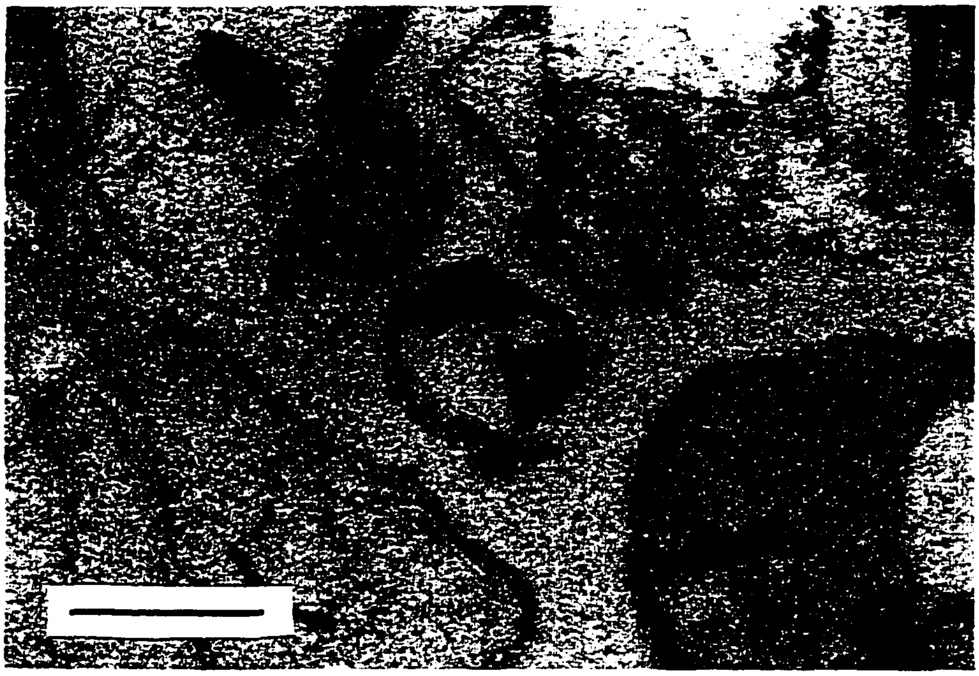


Figure 2-6. The photomicrograph above is of the Success parent material treated with the high concentration of forest floor leachate. The small line is 0.05 cm in length. The grains treated with the high concentration of DOC have noticeably thicker and darker grain coatings than soils treated with nitric acid or lower concentrations of DOC.

Abundance of grain coatings following leaching

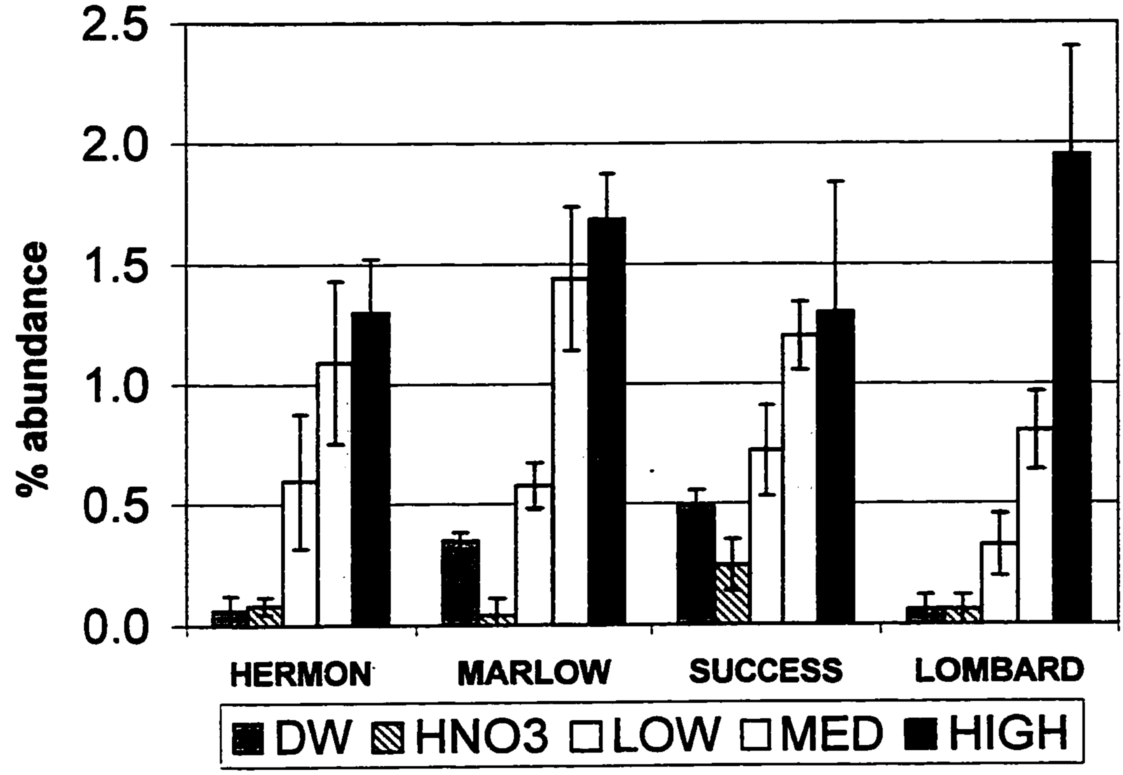



Figure 2-7. The net abundance of cutans (treatment – original parent material) on grains following the one year weathering experiment. The error bars are for one standard deviation. For all samples, n=3.

Relationships between abundance of grain coatings and measures of soil organic carbon

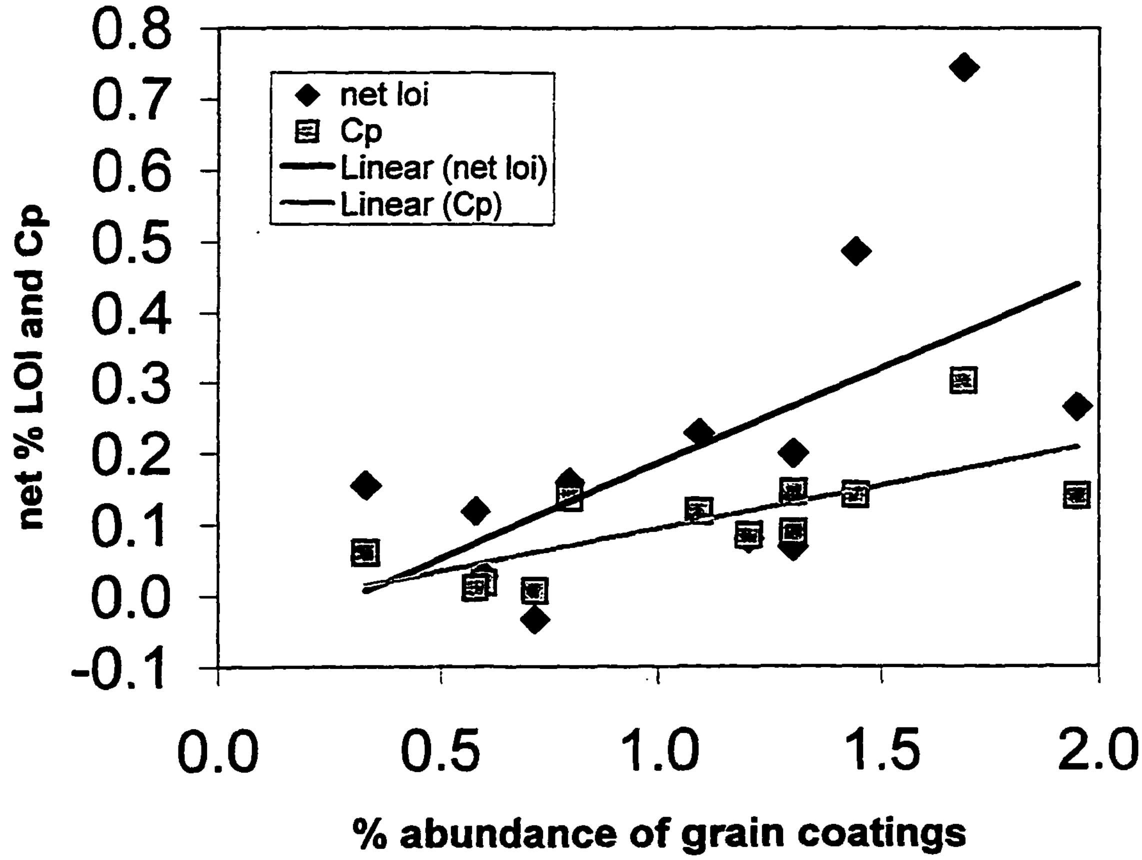



Figure 2-8. Net abundance of cutans (cutans on DOC treated soils – cutans on distilled water treated soils) as a function of net % LOI ($r = 0.77$) and net % Cp ($r = 0.82$).

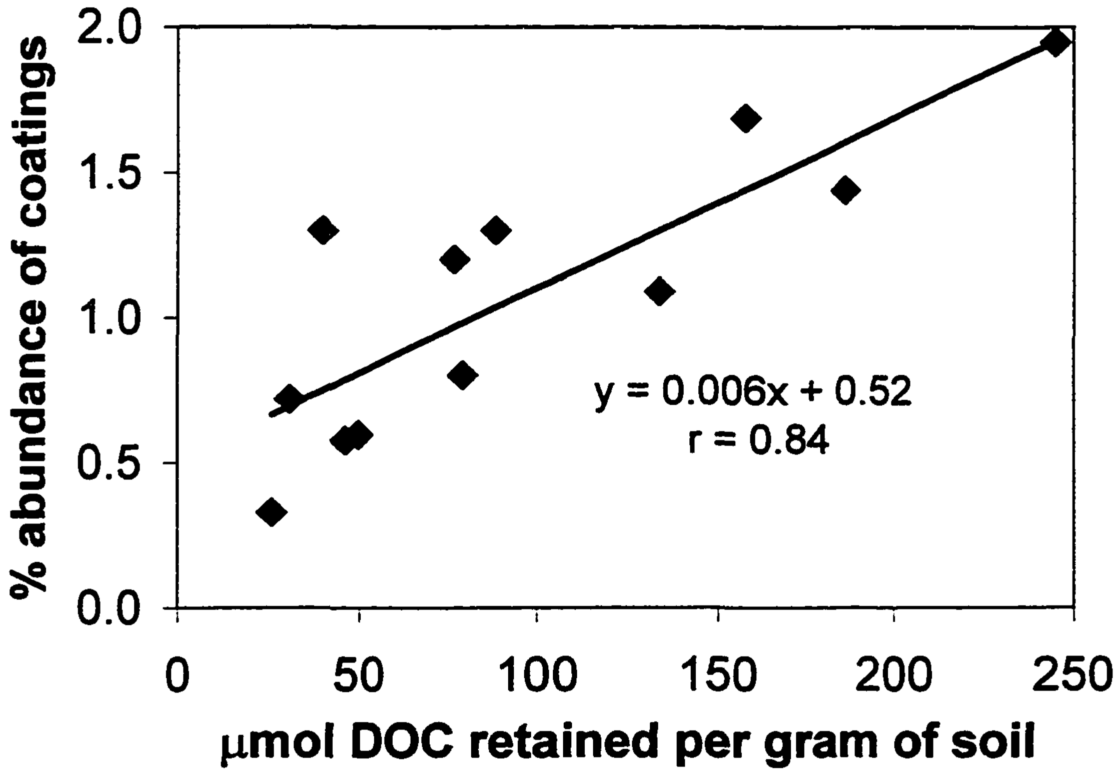



Figure 2-9. Net DOC retention (μmol C/g soil) as a function of net abundance of coatings ($r = 0.84$).

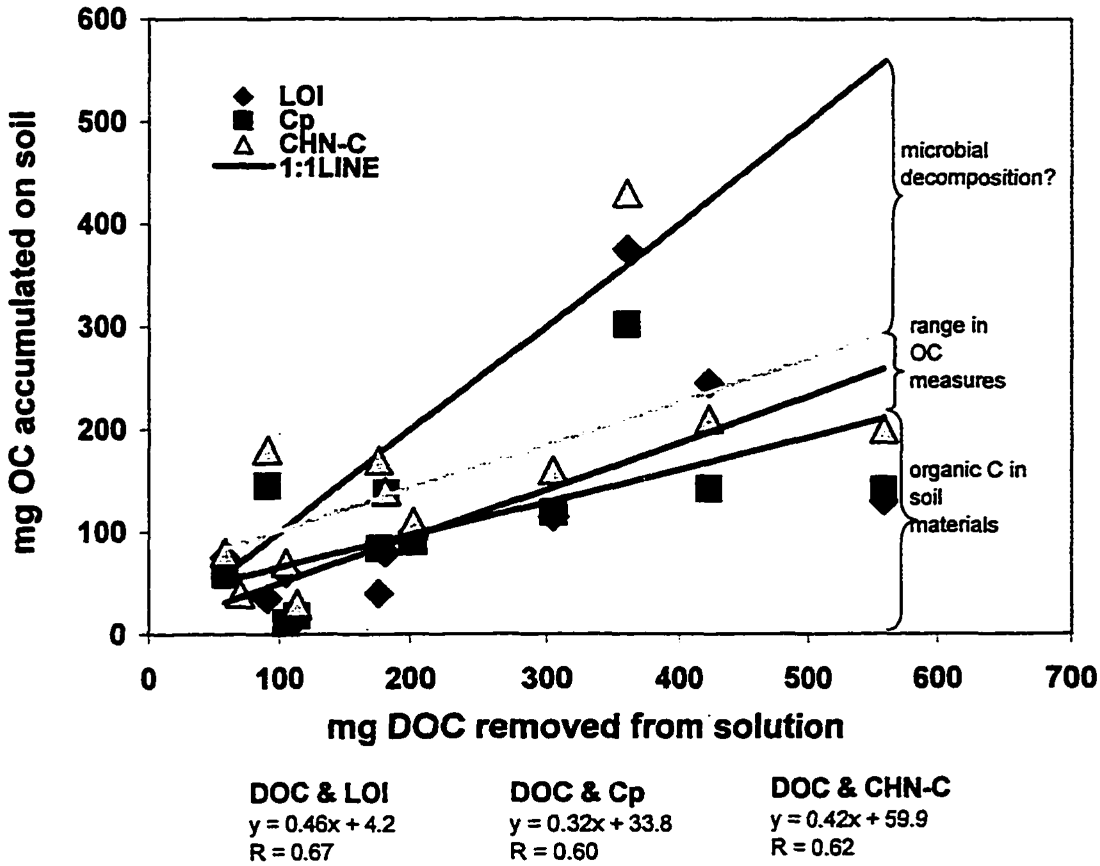



Figure 2-10. The relationships between solution (net DOC retention) and soil measures of net organic carbon retention (net change in % loss on ignition, pyrophosphate extractable C and CHN-C). Percent loss-on-ignition is assumed to be 50% organic carbon in this investigation. See text for further details. The 1 : 1 line is the relationship expected if abiotic retention on mineral soil is the sole mechanism of organic carbon accumulation.

Distribution of Al release

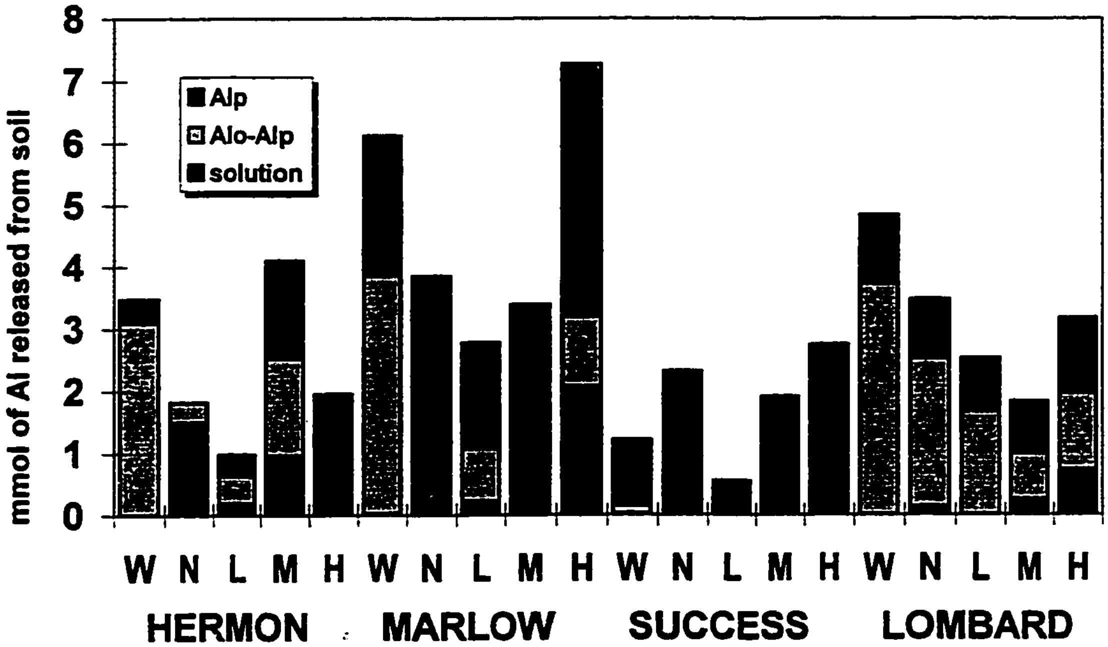



Figure 2-11. Distribution of Al release from soil materials (release to solution and net change in coatings). Letters indicate the solution treatment (W = distilled water; N = nitric acid; L = FF-low; M = FF-medium and H= FF-high).

Distribution of Si release

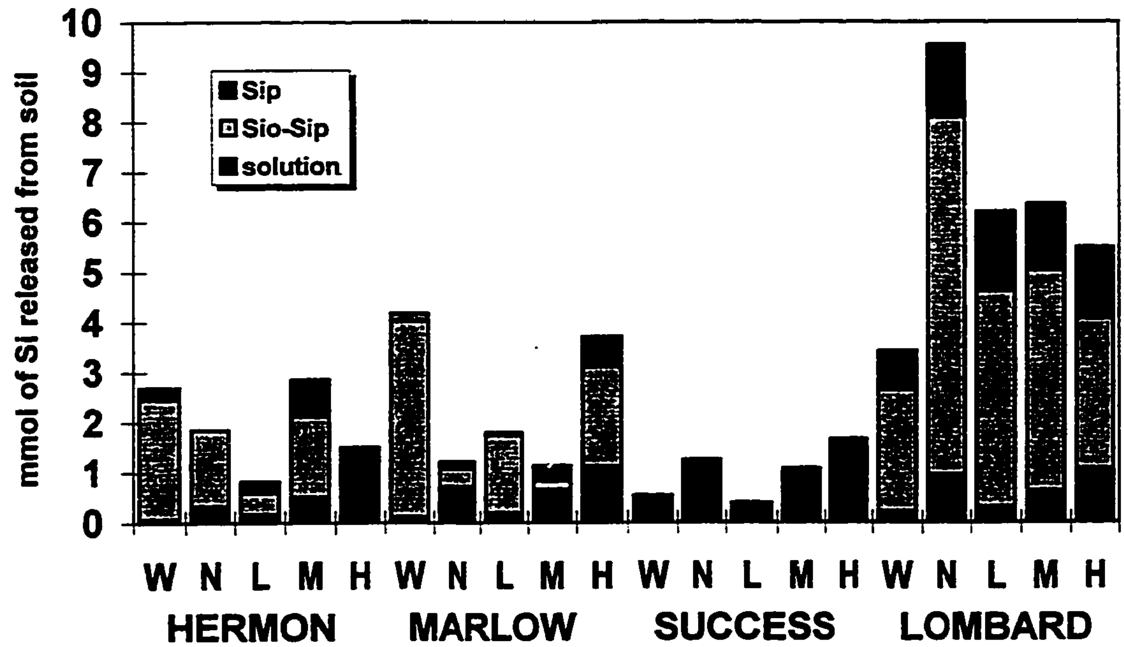



Figure 2-12. Distribution of Si release from soil materials (release to solution and net change in coatings). Letters indicate the solution treatment (W = distilled water; N = nitric acid; L = FF-low; M = FF-medium and H= FF-high).

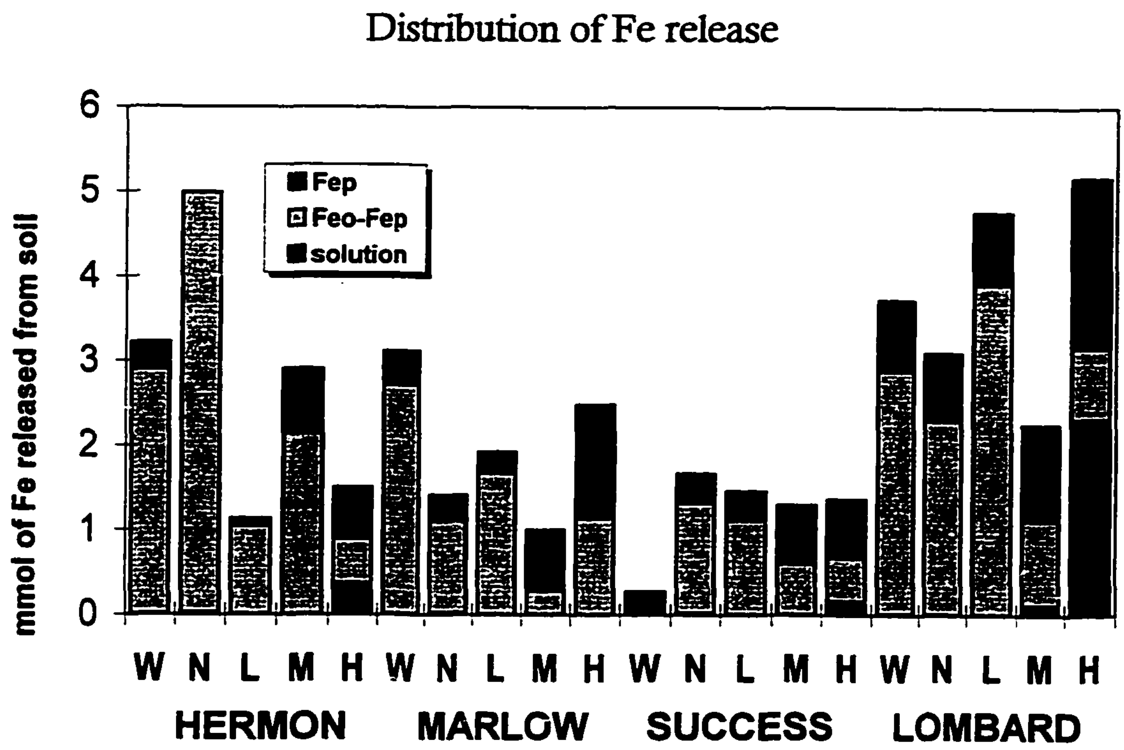



Figure 2-13. Distribution of Fe release from soil materials (release to solution and net change in coatings). Letters indicate the solution treatment (W = distilled water; N = nitric acid; L = FF-low; M = FF-medium and H= FF-high).

CHAPTER III.

# INFLUENCES OF SOIL CHEMICAL AND PHYSICAL PROPERTIES ON DOC CONCENTRATIONS IN FOREST SOILS

## Introduction

The chemical and physical characteristics of soil that are important in controlling DOC retention have been examined in numerous investigations. Jardine et al. (1989) examined the influence of native soil organic carbon (OC) by conducting DOC sorption experiments with and without removal of soil OC. DOC sorption increased in soils where the OC was removed. Studies by Moore et al. (1992) and Dalva and Moore (1991) indicate that there is a positive relationship between equilibrium concentrations of DOC and indigenous soil OC content. Kaiser et al. (1996) noted that soil samples with high amounts of soil OC exhibited lower DOC sorption capacities than soils with lower soil OC contents. Several investigations have also noted strong relationships between DOC sorption and soil chemical and mineral composition. For example, DOC retention has been correlated to HCl-extractable Fe and Al (McDowell and Wood 1984), and dithionite-extractable Fe (Jardine et al. 1989; Moore et al. 1992). High amounts of Al and Fe compounds in lower soil horizons have been correlated with low concentrations of DOC in soil solution (Driscoll et al. 1985; Moore 1989; Lundstrom 1993). However, no study has systematically examined whether mineralogy or surface area is the dominant factor controlling DOC adsorption. Because the clay-sized fraction is typically enriched in phyllosilicates and sesquioxides (Bohn et al. 1985), it becomes exceedingly difficult to distinguish the influence of mineralogy from surface area in the field. Previous laboratory investigations indicate surface area is a major physical factor controlling DOC sorption to commercial grade Fe-oxides and Fe-hydroxides (Tipping 1981) and soil materials with a range of chemical and physical properties (Kaiser et al. 1996). Fahey and Yavitt (1988) and Nelson et al.

(1993) noted that retention of DOC in field soils was positively correlated with clay content. Soils with high amounts of sand adsorbed less DOC than finer textured soils. Soil texture and surface area, coupled with soil solution contact time, have been proposed as key determinants regulating DOC retention by mineral soils (Vance and David 1992; Easthouse et al. 1992; Lundstrom 1993; Nelson et al. 1993).

The behavior of DOC in soils is determined by several biological, chemical and physical processes. In field investigations, it is often difficult to assess the importance of each of these processes in determining the net sorption of DOC in the soil. However, in the laboratory, experimental conditions can be controlled so that the effect of individual sorption phenomena can be identified. Previous investigations have provided much useful information concerning the controls on DOC retention in forest soils. However, there is still a need to better align laboratory settings with natural field conditions. Some of the previous investigations have used commercial grade "soil"-materials (Tipping 1981); high or uncontrolled temperatures (Moore et al 1992; Dalva and Moore 1991) which make it impossible to separate microbial utilization of DOC from DOC sorption; grinding (Dalva and Moore 1991) of soil materials which exposes fresh mineral surfaces; DOC solutions which are not native to the soil materials (peat extracts and/or stream samples) (Jardine et al. 1989; Moore et al 1992); use of single organic acids or fractions (e.g. humic acid) (Huang et al. 1977; Cornell and Schindler 1980; Schulthess and Huang 1991) and use of high solution : soil ratios (Jardine et al. 1989; Moore et al 1992). Several authors have stressed the need for controlled laboratory experiments which resemble field conditions as much as possible so that the mechanisms controlling DOC concentrations can be isolated and the results applied to field situations.

Quantification of DOC retention is frequently examined in a laboratory setting using traditional adsorption isotherms to determine the amount of material in solution that can be adsorbed by soil surfaces as a function of the equilibrium concentration of the solute (Bohn et al. 1985; Thurman 1985). This concept has been applied to studies involving DOC retention in soils using a simple partitioning model, termed initial mass (IM) isotherms (Nodvin et al. 1986), and null-point DOC concentrations ($DOC_{np}$) (Moore et al. 1992) to evaluate equilibrium between DOC in solution and that which is retained on soil particles. In studies conducted by McDowell and Wood (1984) and Moore et al. (1992), equilibrium DOC concentrations exhibited a strong correlation with soil horizon, though there was considerable variation within each of the horizon groupings. Moore et al. (1992) found > 90% of DOC adsorption to mineral surfaces occurs within the first 24 hours of experiments; McDowell and Wood (1984) reported DOC adsorption reached equilibrium in approximately 2 hours. Although adsorption isotherms may yield important information regarding the potential DOC retention capacity of the soil at equilibrium, field conditions rarely, if ever, mimic equilibrium conditions established in the laboratory. Thus, it is questionable whether the results of adsorption isotherm experiments should be applied to field settings.

The objectives of this investigation were: 1) To examine relationships between DOC retention capacity and soil properties commonly reported in pedological and ecological investigations; 2) To examine the relative importance of soil surface area and soil chemical/mineralogical composition in retention of DOC; and 3) To determine if DOC sorption in laboratory batch studies mimics DOC dynamics exhibited in soil solution lysimeter investigations. Additional goals of the investigation were to isolate specific parameters controlling DOC retention while minimizing differences between laboratory and field settings by using natural, heterogeneous soil materials and solutions as recommended by numerous investigators (Davis 1982; Casey et al 1993; Santore et al 1995). Greater similarity between laboratory investigations and natural conditions provides increased understanding of the dynamics of DOC mobility in soils.

## Materials and Methods

### Dissolved Organic Carbon

Forest floor material was collected from a field site in Berlin, NH. Vegetation at the site was dominated by red spruce (*Picea rubens*), white pine (*Pinus strobus*), paper birch (*Betula papyrifera*), and sugar maple (*Acer saccharum*). DOC solutions were prepared by soaking forest floor material (pH 4.0; 1g soil : 10 mL water) in distilled water for 3 days. The solution was then filtered with a 0.45μm nylon filter. The concentrated DOC stock solution was frozen (less than one week) to prevent microbial degradation. One day prior to the batch experiments, the stock solutions were thawed and diluted with distilled water to yield solutions with DOC concentrations ranging from 0 to 95 mg C/L. Solutions were stored overnight at 4 C, the temperature at which all experiments were conducted. The concentration of DOC in the solutions was determined using a Shimadzu Total Organic Carbon Analyzer (TOC-5000).

Experiment One: Controls on DOC Concentrations in the Soil Profile

Soil materials. Four pedons of the Success series (sandy-skeletal, mixed, frigid, ortstein Typic Haplorthods) in Berlin, NH were described and sampled at the Berlin field site. The Success series parent material is derived from glacial till formed from granite and gneiss which overlies an Ordovician-aged metamorphosed volcanic complex, the Ammonoosuc Formation. Soil samples were air-dried and gently crushed to break apart peds. Soil materials were not pre-treated by grinding or with any chemical treatment. The whole soil fraction, including the > 2 mm fraction, was used for the batch experiments because the dynamics of soil - solution interactions in the coarse materials (sandy-skeletal) was likely not well represented by using only the < 2 mm fraction. The < 2 mm size fraction was used for the soil chemical tests to conform to standard analytical methods and those found in the Natural Resources Conservation Service (NRCS) Soil Survey Laboratory Manual. Particle size distribution was determined using the hydrometer method. The pH of the < 2 mm fraction was measured in water and 0.01 M $CaCl_2$ using a soil : solution ratio of 1:1 and 1:2 respectively. Soil organic carbon, dithionite-citrate extractable Fe ($Fe_d$) and Al ($Al_d$) and $NH_4OAC$ extractable bases, acidity, cation exchange capacity, extractable Al, % Al saturation and % base saturation were determined using standard NRCS methods (Soil Survey Laboratory Staff 1996).

Soil solution. Soil solution was monitored for two years at the Berlin field site to examine the chemistry of the natural soil water as it percolates through the soil profile and compare these findings with results of the laboratory batch investigations. Soil solution was collected using Prenart Super Quartz PTFE (teflon) porous cup tension lysimeters. These lysimeters were used because of their low level of Al and Si contamination and the reduced disturbance effect associated with installation relative to zero-tension and other tension lysimeters (Beier and Hansen 1992). Lysimeters were installed above and below the spodic horizon of each pedon. Lysimeter tension was applied for a 24-hour period prior to sampling and set to slightly exceed natural soil tension as measured by tensiometers installed at the sites. Soil solution samples were collected on an event basis during the frost-free season. Solution DOC was measured using a Shimadzu TOC-5000. Inorganic constituents in solution were measured using a Beckman DCP.

Experiment 2: Soil Surface Area Control of DOC Retention

Soil materials. Soil samples were collected from the C horizon of 2 podzolic soil profiles in northern New Hampshire, representing the Success and Hermon soil series. The Hermon series (sandy-skeletal, mixed, frigid Typic Haplorthods) parent material is derived from glacial till formed from Conway Granite and samples were collected in North Conway, NH. The Success series samples were collected from the field site in Berlin, NH. Bulk samples were collected, air-dried and sieved to four size ranges -- 53-63, 105-125, 212-250 and 425-500 μm. The soil materials were then sonified and rinsed with distilled water until the solution was visibly clear of suspended particles. The soil materials were not ground or cleaned with strong acids or peroxide treatments commonly used for sorption and surface area experiments as the validity of these treatments is questionable when attempting to simulate natural soil conditions (Davis 1982). The BET surface area of each size fraction for both parent materials was determined using a krypton adsorbate (Micromeritics, Inc., Norcross, GA). The four size fractions from each parent material were combined to create three samples from each parent material with surfaces areas of 1.0, 2.0 and 3.0 $m^2$ of soil surface area per gram of soil. The mineralogy of each sample (2 parent materials x 3 surface areas = 6 samples) used for this investigation was determined using x-ray diffraction analysis and chemically analyzed for major elements by XRF (XRAL Inc., Ann Arbor, MI). Sodium pyrophosphate-, ammonium oxalate, and citrate-dithionite extractable Al and Fe were determined following the methods of the NRCS (Soil Survey Laboratory Staff 1996)

Sorption Experiments

A preliminary investigation following the methods of Nodvin et al. (1986) was conducted to determine the parent material (PM):solution ratio as well as the length of time necessary for equilibrium (no further sorption). Our preliminary investigations indicated that adsorption was essentially complete within three hours. A soil : solution ratio of 1 g soil : 5 mL of solution was used for both sets of batch experiments. For Experiment 1 (DOC retention in the soil profile), 8 g of soil was combined with 40 mLs of solution (range of DOC concentrations, 0 to 95 mg C/L). There were 3 replicates of each treatment (soil sample from same horizon in one concentration of DOC solution) in Experiment 1. For Experiment 2 (Surface area control of DOC retention), 20 mL of each DOC solution (concentration range 0 to 30 mg C/L) was added to four grams of each soil. There were four replicates for each treatment in Experiment 2. All batch experiments were conducted in HDPE bottles and held at 4 C in the dark for 3 hours. Samples in the batch reactors were gently swirled at the beginning of the experiments. Following the three-hour soil – solution contact, solutions from both experiments were filtered again with a 0.45 μm nylon filter to remove the mineral material.

Total DOC (mg) retained by the samples following the batch investigations was plotted against the initial amount of DOC added (mg) using the initial mass isotherm approach of Nodvin et al. (1986). The linear regression of DOC sorption vs. initial DOC added was calculated using the following equation:

$$RE = m\,Xi - b$$

where:

RE is the release of DOC (mg / g of soil)

$m$ is the regression coefficient

Xi is the amount of DOC in solution (mg /g of soil)

b is the y-intercept (mg / g of soil)

The intercept of the sorption isotherm and the x-axis is termed the null-point concentration of DOC ($DOC_{np}$), the concentration at which there is no net adsorption or desorption of DOC (Moore et al. 1992). The intercept (b) of the isotherm and the y-axis is equivalent to the amount of DOC released at 0 input of DOC, and thus may be called a desorption term. The distribution coefficient, $K_d$, was calculated using the regression coefficient, m, and the ratio of solution to soil as follows:

$$K_d = \frac{m * (\text{volume of solution})}{(1 - m) * (\text{mass of soil})}$$

The reactive soil pool (RSP), the amount of C in the soil materials that can readily exchange with carbon in solution (Nodvin et al., 1986) was calculated using the regression coefficient, m, and the intercept, b, as follows:

$$RSP = \frac{b}{(1 - m)}$$

Relationships between sorption parameters (equilibrium DOC concentration and RSP carbon) and the physical and chemical characteristics of the soil samples were examined using Pearson's correlation. For all statistical analyses, a significance level of $p \leq 0.05$ was selected.

## Results:

### Experiment 1:

The E horizons have the lowest pH values (in both water and $CaCl_2$) of any of the horizons (Table 3-1). Organic carbon content is lowest in the E and BC(m) horizons ( < 2.0 %) and highest in the Bhs horizons ( > 5.1 %). Dithionite extractable Al and Fe, acidity and cation exchange capacity peaked in the spodic horizons of all pedons. All soil samples were very coarse, with over 50 % of the < 2 mm fraction being sand, and many samples contained over 70% sand (Table 3-1).

Most of the samples (all but 4) had more than 10 % > 2 mm particles. The coarse nature of the materials was the reason that the > 2 mm fraction was included in the batch experiments.

DOC adsorption isotherms typically varied by horizon and were well fit by linear regression (Figure 3-1). The $R^2$ values for the initial mass isotherms were $\geq 0.85$ except for the Bhs horizon at Site 5, which had an $R^2$ value of 0.64 (Table 3 -2). All initial mass isotherms had p values < 0.01. Null-point DOC values ranged from 0.60 to 4.60 mg C per gram of soil, equivalent to 15.1 to 116 mg C per L of solution (Table 3-2) for the experimental conditions used in this investigation. Generally, within a given soil pedon, the equilibrium concentration of DOC decreased with depth in the soil profile (Figure 3-2). The mean values for m and $K_d$ for the Bs horizons were typically higher than the mean values for the other horizons. Values for the Reactive Soil Pool (RSP), the amount of carbon in the soil that can readily exchange with carbon in solution under the conditions of the experiment (Nodvin et al 1986), ranged from 0.26 to 1.69 mg DOC per gram of soil. The mean RSP value for the E horizons (1.23) was higher than for the other horizons. The BC(m) horizons had the lowest mean RSP value.

The equilibrium concentration of DOC was correlated with $pH_{CaCl2}$ ($r = -0.77$; $p < 0.005$) (Figure 3-3a) and the amount of ammonium acetate extractable bases ($r \geq 0.81$; $p < 0.001$) for all horizons. $DOC_{np}$ and the reactive soil pool of carbon (RSP) both had strong negative relationships with $pH_{CaCl2}$ indicating that the net DOC retention of these soils increased with increasing pH in Experiment 1. $DOC_{np}$ values in B horizons (Bhs, Bs, and BC) were strongly related to many soil chemical properties, including % OC, Cp and CEC (all positive relationships), as well as pH and extractable bases. For E horizons, the equilibrium concentration of DOC did not fit well into the linear regression models established for the relationships between $DOC_{np}$ and soil properties for B horizons, including the % OC ($r > 0.72$; $p < 0.012$) (Figure 3-3b). The percent organic carbon in B horizons was correlated with the sorption parameters b (Figure 3-4) and RSP, r = -0.86 and 0.82, respectively. DOC retention was not correlated with other soil chemical characteristics commonly reported in ecological and pedological investigations such as dithionite extractable Fe and Al, % Al saturation, and acidity. Soil particle size distribution was not effective in explaining the sorption of DOC in these coarse materials.

Trends in soil solution chemistry collected at the Berlin field site show patterns of Al, Fe and DOC retention common in podzolized soils (Table 3-3). The trends in DOC sorption exhibited in the laboratory batch study are similar to patterns of DOC concentrations in field soil solutions. Soil E horizons show little affinity for DOC, as illustrated in Table 3-3 by the high concentrations of DOC in the soil solution leaving the E horizons (range 31.5 to 75.3 mg C/ L of solution; mean value 55.3 mg C/L). The solution draining from the Bs horizons has a much lower concentration of DOC (range 5.3 to 17.6 mg C /L of solution; mean 13.3 mg C/L).

Experiment 2:

$SiO_2$ was the dominant constituent all of soil materials used in Experiment 2 (range 68.9 - 78.5) (Table 3-4). $Al_2O_3$ was also abundant in all samples (range 10.9 - 14.3). The Success soils had a slightly higher $Al_2O_3$ and $Fe_2O_3$ content than the Hermon soil materials. The Hermon and Success parent materials contained similar minerals, both having quartz, albite, biotite and plagioclase. The quantities Al and Fe extracted by the citrate-dithionite, ammonium-oxalate and sodium pyrophosphate solutions were all very low ( $\leq$ 0.16 %), and thus the differences between samples were small. The peak in quantities of extractable Al and Fe for each parent material typically occurred in the samples with the intermediate surface area (2 $m^2/g$) (Table 3-5).

All isotherms were adequately described by a linear regression model with the concentrations of DOC ($\leq$ 30 mg C / L) used in this experiment. The $R^2$ values for the initial mass isotherms were $\geq$ 0.89 ($p < 0.001$). Null-point DOC values ranged from 0.18 to 0.34 mg C per gram of soil (Table 3-6), which was equivalent to 9.0 to 17.1 mg C per L of solution for the experimental conditions used in this investigation. For both soil parent materials investigated, the highest equilibrium DOC concentration was for the intermediate surface area (2.0 $m^2/g$ of soil) samples (Figure 3-5). For all paired surface area samples, the Success soils had a higher equilibrium DOC concentration by 3.0 mg C/L or more (mean difference = 3.8 mg C/L). The Hermon soil with 1.0 $m^2/g$ soil had the lowest equilibrium DOC concentration (9.0 mg C/L) and the Success soil with 2.0 $m^2/g$ of soil had the highest equilibrium DOC concentration (17.1 mg C/L). Additionally, in both soil materials, the highest equilibrium DOC concentration, regression coefficient, distribution coefficient and value for RSP were found for the 2.0 $m^2/g$ of soil samples.

There was no clear trend between the equilibrium concentration of DOC and soil surface area ($r = 0.46$). For both the Hermon and Success soil materials, the highest equilibrium DOC concentration was for the 2.0 $m^2/g$ samples. The equilibrium concentration of DOC was correlated with $Fe_2O_3$ ($r = 0.82$; $p < 0.05$), $Al_2O_3$ ($r = 0.81$; $p < 0.05$) and LOI ($r = 0.75$; $p < 0.07$). The equilibrium concentration of DOC was also correlated with dithionite extractable Fe ($r = -0.98$; $p < 0.01$) (Figure 3-6) and pyrophosphate extractable Al ($r = 0.92$; $p < 0.01$) and Fe ($r = 0.88$; $p < 0.02$). The relationships between RSP and soil extractable Al and Fe were not as strong as those between equilibrium DOC concentration and extractable Al and Fe.

## Discussion:

My results indicate a direct relationship between $DOC_{np}$ and % OC in the B horizons studied suggesting that equilibrium between soils and dissolved phases drives DOC dynamics in mineral soils. This relationship is in agreement with previous results that suggest that indigenous soil OC may inhibit sorption of additional OC (Jardine et al. 1989; Dalva and Moore 1991; Guggenberger and Zech 1993; Zech et al. 1994). Soil organic carbon is frequently cited as one of the main factors controlling the concentration of DOC in soil solution (Jardine et al. 1989; Dalva and Moore 1991; Kaiser et al. 1996). Kaiser et al. (1996) noted that in soils leached with distilled water, the release of DOC was primarily controlled by the content of soil OC. Similar results were found in the Moore et al. (1992) investigation. Several studies have also reported that DOC adsorption may be hindered in soils containing significant quantities of OC. Investigations of DOC dynamics in mineral soils with high concentrations of OC have reported low DOC adsorption or net DOC desorption (Jardine et al. 1989; Dalva and Moore 1991; Guggenberger and Zech 1993; Zech et al. 1994). In this investigation, the E horizons do not fit well into this relationship (Figure 3-3b). The differences between the sorption capacities of E and B horizons may be attributed to differences in the content of extractable Al and Fe (oxides or organically complexed) or may be a function of differences in the chemical composition of the soil organic matter in E and B horizons. The difference in sorption potential between E and B horizons was also noted by Kaiser et al. (1996) and Moore (1997). Vance et al. (1986) examined differences in phenolic compounds in soil organic matter in several podzolized soils. Results of their investigation indicate that soil organic matter in E and B horizons contains different quantities of some phenolic compounds. Specifically, protocatechuic acid was found in much higher concentrations in spodic horizons than in E horizons. Maximum concentrations of protocatechuic acid coincided with peaks in $Al_p$ and $Fe_p$ in Bs horizons (Vance et al. 1986). There may be additional biological, chemical or physical factors controlling humification which may yield E horizon OC more susceptible to leaching (Duchaufour 1976).

Examining the $DOC_{np}$ pattern of the horizons, moving down the soil profile (E $\rightarrow$ BC) the equilibrium concentration of DOC declines with depth (Figure 3-2). This pattern of DOC retention was also reported by McDowell and Wood (1984) and Moore et al. (1992). In the soils used in this study the E horizons had a low OC content relative to the B horizons, some E horizons had even less soil OC than the BC(m) horizon of the same profile. The high $DOC_{np}$ values for E horizons clearly is the exception to the pattern of increased $DOC_{np}$ with increased % OC (Figure 3-3b). Desorption of DOC from E horizons at 0 addition of DOC (as indicated by b, the y intercept value) was much higher than from soil horizons with higher amounts of OC (Figure 3-4). The soil Bhs horizons had the highest OC content (mean value 6.7%) of any of the soil horizons yet still had a lower mean $DOC_{np}$ than the E horizons. This pattern of $DOC_{np}$ values for E horizons indicates other chemical or physical properties in the soil materials had a significant impact on the equilibrium concentration of DOC in these soil materials.

In relatively unweathered soil materials (Experiment 2), equilibrium concentrations of DOC were highly correlated with small differences in extractable quantities of Al and Fe, despite differences in surface area. DOC retention had especially strong relationships with dithionite extractable Fe (Figure 3-6), and pyrophosphate extractable Al and Fe. There were positive relationships between the equilibrium concentration of DOC and Alp and Fep ($r = 0.88$, $p < 0.02$), illustrating that DOC sorption is lower in soils with higher contents of pyrophosphate extractable Al and Fe. This pattern may be attributed to the content of OC in these materials, as pyrophosphate is frequently used to remove "organically-bound" Al and Fe. There was an indirect relationship between $Fe_d$ and $DOC_{np}$ ($r = -0.98$, $p < 0.01$) in this investigation indicating that soil materials with low amounts of $Fe_d$ are not strong scavengers of DOC (high $DOC_{np}$). Results from Experiment 2 are in agreement with findings from Experiment 1 where the eluvial E horizons which were poor in extractable Fe and Al relative to the spodic Bhs and Bs horizons had the highest $DOC_{np}$ values indicating a low capacity for DOC sorption at low DOC concentrations. The B horizons (including the BC(m) horizons) were efficient scavengers of the DOC in the input solutions as suggested by the lower $DOC_{np}$ values. Even with these horizon differences, there were no significant relationships between $DOC_{np}$ and extractable Al and Fe in Experiment 1, with the more developed soils.

Several investigators have noted relationships between DOC sorption and quantities of extractable Fe and Al (McDowell and Wood 1984; Jardine et al. 1989; Moore et al. 1992). The various extracting agents have been proposed to remove different fractions of Fe and Al. For example, in traditional pedological investigations, dithionite-citrate-(bicarbonate), ammonium-oxalate, and sodium pyrophosphate are generally thought to remove total free (including amorphous and some crystalline), amorphous and organic forms of Al and Fe, respectively (Birkeland 1984). However, there are numerous studies contradicting these generalities (Parfitt and Childs 1988; LaZerte and Findeis 1995; Kaiser and Zech 1996). I chose to use these extracting agents because of their widespread use in ecological and pedological investigations of DOC, but make no assumptions about what forms of Al and Fe are extracted.

DOC sorption to pure Fe and Al oxides and hydroxides has been widely reported (Schnitzer 1969; Parfitt et al. 1977; Tipping 1981; Davis 1982). Many of these inorganic mineral coatings have at least some exchange sites with a positive charge (or pH-dependent charge, which are positive at low pH values) and thus form surface complexes with organic functional groups (e.g. carboxylic and phenolic groups). These laboratory results have been confirmed using soil (Jardine et al. 1989) and aquifer materials (Barber et al. 1992). DOC sorption has been shown to decrease significantly when soil materials are treated with NaOCl and dithionite-citrate-bicarbonate to remove soil organic matter and Fe oxides/hydroxides. The reduction in DOC sorption capacity was largely attributed to the removal of Fe-oxides and hydroxides, not the removal of SOM (Jardine et al. 1989). In an examination of factors controlling chlorobenzene sorption in sand and gravel aquifer materials, Barber et al. (1992) noted that the Fe-rich magnetic fraction had five to ten times more sediment organic carbon associated with mineral surfaces than the bulk and non-magnetic fractions. The preferential association of OC with the magnetic minerals is consistent with the results of previous investigations (Tipping 1981; Davis 1982; Jardine et al. 1989). The relationship between OC and Fe-minerals is likely the result of surface complexation between organic functional groups and positive charges on mineral grains and grain coatings (Barber et al. 1992).

The equilibrium concentration of DOC was strongly correlated with soil $pH_{CaCl2}$ (negative relationship) and the amount of extractable bases (positive relationship). Soil pH is frequently suggested to play a key role in DOC sorption (Jardine et al. 1989; Vance and David 1989; Rustad et al. 1993) as well as solubilization of soil organic matter (Krug and Isaacson 1984; David et al. 1989; Vance and David 1989). DOC (macro)molecules have both positively- and negatively-charged functional groups but DOC is generally considered an anion. One of the mechanisms of DOC sorption to mineral surfaces is thought to involve exchange of DOC anions for hydroxyl and carboxyl groups on oxide surfaces (Tipping 1981; Kaiser et al. 1996). When soil pH is low, pH-dependent charges will tend to be positive thus increasing the sorption of negatively charged DOC functional groups to the positively charged exchange sites. In soil E horizons where the $pH_{CaCl2}$ was the lowest (mean pH = 3.1), there was a high $DOC_{np}$ indicating increased solubilization of soil OC and low net DOC retention. The pH values in the B horizons were higher (pH range 4.0 to 4.8) than the pH values in the E horizons. This pH range was still low enough to have a significant positive charge on mineral surfaces thus allowing for sorption of negatively charged DOC functional groups. $DOC_{np}$ was also positively correlated with the amount of extractable bases ($r = 0.84$; $p < 0.001$). The direct nature of this relationship was anticipated because soils with a high affinity for DOC anions generally would not effectively retain base cations due to charge properties. The relationship between exchangeable bases and $DOC_{np}$ was improved when E horizons were excluded. Again this trend can be partially explained by the moderate amounts of OC and low content of extractable Fe and Al which yields a lower exchange capacity for ions yet a high amount of carbon leaching. The Bhs horizons with the highest average content of exchangeable bases as well as the most OC and high extractable Al and Fe contents, had intermediate $DOC_{np}$ values. The association between $DOC_{np}$ and extractable bases, as well as other soil chemical properties (e.g. acidity, ext. aluminum, and CEC) were also improved when E horizons were excluded. These relationships further illustrate the complex nature of the chemical processes involved in determining the concentration of DOC in soil solution.

Many studies suggest that soil surface area (or particle size distribution) exerts the most control over DOC sorption. This investigation systematically controlled other variables (% OC, mineralogy, and chemical properties) while varying the surface area of the soil materials and found a weak relationship ($r = 0.46$; $p < 0.36$) between $DOC_{np}$ and surface area (Figure 3-6). Although this part of the investigation was conducted on a small number of samples, it was specifically designed to ascertain if the equilibrium DOC concentration has a simple linear relationship with surface area. Results of this experiment suggest that although surface area may be an important factor it does not dictate DOC sorption in these coarse soil materials, even with minimal differences in other parameters. In the controlled laboratory investigation (Experiment 2) the relationship between surface area was not a simple direct relationship as might be expected from results of other investigations. My results indicate that factors other than surface area control the equilibrium concentration of DOC even in relatively unweathered soil materials (C horizons) with low contents of organic carbon and extractable Al and Fe. The peak in

$DOC_{np}$ for both of the parent materials studies was in the intermediate surface area (2 $m^2/g$) samples which typically coincided with peaks in extractable Al and Fe. In our field-based study, (Experiment 1) $DOC_{np}$ was not well correlated with any of the particle size fractions. The best relationship was with clay ($r = 0.41$). The slope of the isotherm, m, did have a strong positive relationship with the percent silt ($r = 0.72$) and a negative relationship with the percent sand ($r = -0.72$). These trends may indicate that particle size-distribution impacts the equilibrium concentration of DOC and may be more influential over a wider range of soil textures. This evidence suggests that in coarse materials (sandy loams and loamy sands) even small differences in soil chemical characteristics may exert more control over DOC sorption than soil physical characteristics. Surface area differences controlling DOC concentrations reported in other investigations may also be related to changes in soil mineralogy common in the soil fine fraction.

Several investigators have examined the relationships between measures of surface area and particle size distribution and the content of soil organic carbon and DOC sorption (Davis 1982; Barber et al. 1992; Nelson et al. 1993). Following examination of much OC and surface area data from soils and sediments, Mayer (1994 a, b) proposed that soil and sediment OC content is controlled by monolayer coverage of mineral surfaces by carbon. In typical soil A horizons, monolayer coverage would be equal to 5-40 mg C / gram of soil (or 0.5 to 4.0 % OC). In our field based investigation (Experiment 1) all soil horizons with the exception of the Bhs horizons were within the monolayer coverage range. Although the anticipated outcome of the sorption experiments based upon previous investigations of DOC sorption and examinations of OC content in different particle size fractions of soils and sediments (Barber et al. 1992; Nelson et al 1993; Mayer 1994 a, b; Kaiser et al. 1996) was increased DOC sorption with increased surface area, other investigators have noted anomalies in this relationship. For instance, McCracken (Chapter 1) examined DOC retention patterns in four parent materials in a laboratory column study and found a poor relationship between the surface area of the materials and the amount of DOC retained. Additionally, Ball et al. (1990) found increased OC and sorption with increasing particle size for sandy aquifer material from Ontario, Canada. Such conflicting results indicate the need for detailed consideration of physical and chemical properties of soil and sediments when attempting to couple hydrological and geochemical processes.

In our investigation of the controls on DOC concentrations in the soil profile (Experiment 1), laboratory and field results indicate increasing DOC retention capacity with depth in the soil profile (Figures 3-2, 3-7). The E horizons had low contents of OC and extractable Al and Fe as well as a low pH. These chemical characteristics are consistent with the eluvial nature of E horizons. Given the low pH and low OC content, the E horizons might be expected to readily sorb additional DOC. However, most of the mineral grains are highly leached and there is little accumulation of Al and Fe oxide/hydroxide grain coatings. The abundance of extractable Al and Fe is frequently suggested to be a primary factor in DOC retention (Tipping 1981; Jardine et al. 1989). As illustrated by our laboratory batch studies, not only do E horizons fail to retain significant quantities of DOC given the concentrations of DOC commonly found in soil solutions percolating from the forest floor and soil E horizons (Table 3-7), but with the high equilibrium concentrations of DOC in the E horizons, desorption or solubilization of OC is more likely to occur than DOC sorption. The spodic horizons (Bhs and Bs) had higher amounts of OC and extractable Al and Fe as well as a higher pH than the E horizons. Again, given the pH and OC content, low retention of DOC might be expected in these soil horizons. However, the increased content of Al and Fe oxides makes the spodic horizons efficient scavengers for DOC in solution. The high sorption capacity of spodic horizons has been widely documented in field investigations through examination of soil chemistry (Buurman 1985; Vance et al. 1986; Olsson and Melkerud 1989) and soil solution (Table 3-7). Results of our laboratory batch studies as well as lysimeter solutions are in agreement with these previous results.

Table 3-1. Physical and chemical characteristics of the soil samples used in batch Experiment 1.

| SITE | HORIZON | pH $H_2O$ | pH $CaCl_2$ | OC | $Fe_d$ | $Al_d$ | Al sat. | ext. bases† | acidity | CEC‡ | > 2mm | clay | silt | sand |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | ——— | —— % | —— | ——— | ——— | cmol / kg | ——— | % of total | – % of < 2mm – | | |
| 1 | E | 3.7 | 3.2 | 1.1 | 0.3 | 0.1 | 74 | 0.9 | 8 | 6 | 10 | 3 | 37 | 60 |
| 1 | Bhs | 4.6 | 4.1 | 7.8 | 2.8 | 2.0 | 90 | 0.9 | 68 | 42 | 25 | 3 | 33 | 65 |
| 1 | Bs | 5.0 | 4.5 | 3.8 | 1.6 | 1.5 | 74 | 0.5 | 41 | 23 | 32 | 2 | 29 | 69 |
| 1 | BCm | 5.3 | 4.4 | 2.0 | 0.5 | 0.6 | 50 | 0.2 | 21 | 8 | 26 | 1 | 13 | 86 |
| 3 | Bhs | 4.9 | 4.3 | 5.1 | 2.1 | 1.7 | 14 | 0.6 | 44 | 26 | 6 | 2 | 46 | 53 |
| 3 | Bs | 4.9 | 4.5 | 3.6 | 2.9 | 1.6 | 80 | 0.1 | 38 | 17 | 5 | 2 | 44 | 55 |
| 3 | BC | 5.1 | 4.8 | 2.4 | 1.7 | 1.0 | 67 | 0.2 | 25 | 12 | 7 | 2 | 42 | 56 |
| 4 | E | 3.7 | 3.2 | 1.4 | 0.1 | 0.1 | 20 | 0.4 | 8 | 7 | 8 | 2 | 24 | 74 |
| 4 | Bs | 4.7 | 4.3 | 2.7 | 1.6 | 0.8 | 82 | 0.3 | 30 | 16 | 12 | 3 | 27 | 71 |
| 4 | BC | 5.1 | 4.5 | 0.7 | 0.6 | 0.2 | 50 | 0.1 | 7 | 3 | 37 | 1 | 10 | 89 |
| 5 | E | 3.5 | 3.0 | 1.0 | 0.3 | 0.1 | 78 | 0.5 | 8 | 7 | 11 | 2 | 27 | 71 |
| 5 | Bhs | 4.5 | 4.0 | 7.3 | 1.6 | 1.6 | 88 | 0.6 | 59 | 38 | 32 | 1 | 19 | 79 |
| 5 | Bs | 4.7 | 4.2 | 4.2 | 1.2 | 1.2 | 81 | 0.3 | 44 | 26 | 38 | 1 | 16 | 83 |
| 5 | BCm | 4.9 | 4.3 | 1.1 | 0.3 | 0.4 | 67 | 0.1 | 17 | 8 | 21 | 1 | 6 | 93 |

† sum of extractable bases by $NH_4OAc$

‡ determined by $NH_4OAc$

Table 3-2. Results of batch Experiment 1 using soil materials from the Berlin field site. For all samples, n = 3. All regression relationships were significant at the $p < 0.01$ level.

| site | horizon | m | b | $R^2$ | DOCnp | Kd | RSP |
|---|---|---|---|---|---|---|---|
| | | | | | mg C/L | $m^3$/kg | mg DOC/g |
| 1 | E | 0.27 | -1.24 | 0.98 | 116 | 0.18 | 1.69 |
| 1 | Bhs | 0.24 | -0.66 | 0.96 | 68.1 | 0.16 | 0.87 |
| 1 | Bs | 0.27 | -0.48 | 0.98 | 43.8 | 0.19 | 0.66 |
| 1 | BCm | 0.19 | -0.27 | 0.95 | 36.9 | 0.11 | 0.34 |
| 3 | Bhs | 0.26 | -0.65 | 0.98 | 62.7 | 0.18 | 0.89 |
| 3 | Bs | 0.39 | -0.33 | 0.96 | 21.0 | 0.32 | 0.54 |
| 3 | BC | 0.39 | -0.24 | 0.96 | 15.1 | 0.33 | 0.39 |
| 4 | E | 0.21 | -0.66 | 0.92 | 76.3 | 0.14 | 0.83 |
| 4 | Bs | 0.37 | -0.51 | 0.96 | 33.9 | 0.30 | 0.81 |
| 4 | BC | 0.17 | -0.21 | 0.88 | 32.4 | 0.10 | 0.26 |
| 5 | E | 0.27 | -0.85 | 0.96 | 80.0 | 0.18 | 1.16 |
| 5 | Bhs | 0.26 | -0.58 | 0.64 | 55.5 | 0.18 | 0.79 |
| 5 | Bs | 0.26 | -0.41 | 0.85 | 39.7 | 0.18 | 0.56 |
| 5 | BCm | 0.16 | -0.26 | 0.89 | 40.7 | 0.10 | 0.31 |

Table 3-3. Chemistry of soil solution collected in field lysimeters at the Berlin field site. Data are mean values for the two year collection period.

| | Site 1 | | Site 3 | | Site 4 | | Site 5 | |
|---|---|---|---|---|---|---|---|---|
| | E | Bs | E | Bs | E | Bs | E | Bs |
| | data in mg per liter of solution | | | | | | | |
| DOC | 31.5 | 16.9 | 48.4 | 5.31 | 75.4 | 17.6 | 66.1 | n.d.† |
| Al | 2.10 | 0.70 | 1.73 | 0.26 | 1.95 | 0.77 | 3.10 | n.d. |
| Fe | 0.49 | 0.25 | 0.39 | 0.15 | 0.68 | 0.16 | 0.32 | n.d. |
| Ca | 3.18 | 1.13 | 0.65 | 0.89 | 2.10 | 2.26 | 1.43 | n.d. |
| Mg | 0.46 | 0.34 | 0.06 | 0.12 | 0.70 | 0.61 | 0.12 | n.d. |
| K | 1.55 | 0.40 | 1.13 | 0.80 | 3.10 | 1.95 | 0.24 | n.d. |
| Si | 2.50 | 4.16 | 4.44 | 4.47 | 5.45 | 7.86 | 4.75 | n.d. |

† no data - sufficient sample not collected

Table 3-4. Selected chemical and physical properties of soil materials used in Experiment 2. For all samples, n = 2.

| Parent material | Surface area | $SiO_2$ | $Al_2O_3$ | CaO | MgO | $Na_2O$ | $K_2O$ | $Fe_2O_3$ | MnO | $TiO_2$ | $P_2O_5$ | LOI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $m^2$/gram | percent | | | | | | | | | | |
| Hermon | 1.0 | 77.4 | 11.3 | 0.37 | 0.09 | 3.05 | 4.27 | 1.84 | 0.03 | 0.20 | 0.03 | 0.6 |
| Hermon | 2.0 | 76.5 | 11.2 | 0.46 | 0.37 | 3.02 | 4.25 | 2.18 | 0.04 | 0.29 | 0.03 | 1.0 |
| Hermon | 3.0 | 77.9 | 10.9 | 0.43 | 0.09 | 2.94 | 4.10 | 2.14 | 0.04 | 0.29 | 0.04 | 1.0 |
| Success | 1.0 | 78.5 | 11.2 | 0.96 | 0.19 | 3.42 | 3.12 | 1.05 | 0.02 | 0.14 | 0.03 | 0.9 |
| Success | 2.0 | 72.9 | 13.4 | 1.67 | 0.61 | 3.98 | 3.21 | 2.53 | 0.06 | 0.39 | 0.10 | 1.4 |
| Success | 3.0 | 68.9 | 14.3 | 1.86 | 0.73 | 4.09 | 3.43 | 3.36 | 0.08 | 0.55 | 0.15 | 2.3 |

Table 3-5. Extractable quantities of Al and Fe for the soil materials in Experiment 2. For all samples, n = 3.

| Parent material | Surface area | citrate-dithionite Al | citrate-dithionite Fe | ammonium oxalate Al | ammonium oxalate Fe | sodium pyrophosphate Al | sodium pyrophosphate Fe |
|---|---|---|---|---|---|---|---|
| | $m^2$/gram | percent | | | | | |
| Hermon | 1.0 | 0.08 | 0.16 | 0.09 | 0.09 | 0.02 | 0.02 |
| Hermon | 2.0 | 0.11 | 0.14 | 0.12 | 0.11 | 0.05 | 0.03 |
| Hermon | 3.0 | 0.11 | 0.15 | 0.11 | 0.13 | 0.04 | 0.02 |
| Success | 1.0 | 0.10 | 0.14 | 0.08 | 0.09 | 0.04 | 0.02 |
| Success | 2.0 | 0.11 | 0.10 | 0.12 | 0.08 | 0.06 | 0.04 |
| Success | 3.0 | 0.10 | 0.12 | 0.12 | 0.07 | 0.05 | 0.03 |

Table 3-6. Regression results, null-point DOC and equilibrium DOC concentrations for the six samples used in Experiment 2. For all samples, $n = 4$ and $p < 0.001$ for all isotherms.

| SOIL | Surface area | m | b | $R^2$ | $DOC_{np}$ | Kd | RSP |
|---|---|---|---|---|---|---|---|
| | ($m^2/g$) | | | | mg/L | $m^3/kg*10^{-2}$ | mg DOC/g |
| Hermon | 1.0 | 0.24 | -0.044 | 0.98 | 9.0 | 8.0 | 0.057 |
| Hermon | 2.0 | 0.28 | -0.069 | 0.98 | 12.4 | 9.6 | 0.095 |
| Hermon | 3.0 | 0.23 | -0.053 | 0.98 | 11.6 | 7.3 | 0.068 |
| Success | 1.0 | 0.12 | -0.028 | 0.90 | 12.0 | 3.3 | 0.032 |
| Success | 2.0 | 0.22 | -0.074 | 0.96 | 17.1 | 7.0 | 0.095 |
| Success | 3.0 | 0.18 | -0.055 | 0.94 | 15.2 | 5.6 | 0.068 |

Table 3-7. DOC concentrations in soil solution from several locations.

| AUTHORS | YEAR | LOCATION | SITE/ID | PARAMETER | DOC |
|---|---|---|---|---|---|
| | | | | | mg C/L |
| This Investigation† | 1998 | New Hampshire | | E horizon | 55.3 |
| | | | | B horizons | 13.3 |
| Guggenberger and Zech | 1993 | Germany | Wulfersreuth | min soil input | 27.7 |
| | | | | B horizon 30cm | 2.5 |
| | | | | min soil output 90cm | 1.7 |
| | | | Oberwarmen--steinach | min soil input | 26.6 |
| | | | | B horizon 30cm | 3.8 |
| | | | | min soil output 90cm | 2.2 |
| | | | Hohe Matzen | min soil input | 54.4 |
| | | | | B horizon 30cm | 31.2 |
| | | | | min soil output 90cm | 11.3 |
| Easthouse et al. | 1992 | S. Norway | | O horizon | 10.9 |
| | | | | E horizon | 6.0 |
| | | | | B horizon | 3.4 |
| Dalva &Moore | 1991 | Quebec | 1 | A horizon | 46.0 |
| | | | | B horizon | 16.6 |
| | | | 3 | A horizon | 49.2 |
| | | | | B horizon | 19.4 |
| Edmonds et al. | 1991 | Hoh River Valley Washington | | forest floor | 10.8 |
| | | | | 15cm | 9 |
| | | | | 40cm | 2.9 |
| Moore | 1989 | New Zealand | | surface soil | 55.7 |
| | | | | subsurface soil | 11.8 |
| McDowell & Likens | 1988 | New Hampshire | | E horizon | 33.0 |
| | | | | upper B horizon | 5.9 |
| | | | | B horizon | 3.0 |
| Ugolini et al. | 1988 | Japan | Misi | A2 horizon | 6.6 |
| | | | | Bw horizon | 5.2 |
| | | | Abma | A horizon | 10.7 |
| | | | | Bw horizon | 3.8 |
| | | | | 2Eb horizon | 11.3 |
| | | | | 2Bsmb horizon | 4.6 |
| Ugolini et al. | 1987 | Alaska | boreal forest | Oe horizon | 99 |
| | | | | E horizon | 50 |
| | | | | Bs horizon | 14 |
| | | | | C horizon | 2 |
| | | | arctic tundra | Oe/A horizon | 51 |
| | | | | E horizon | 30 |
| | | | | Bs horizon | 19 |
| | | | | C horizon | 20 |

†Mean values reported here. Values for individual sites are given in Table 3-3; additional data in Appendix B.

## Initial mass isotherms for selected soil horizons from Experiment 1

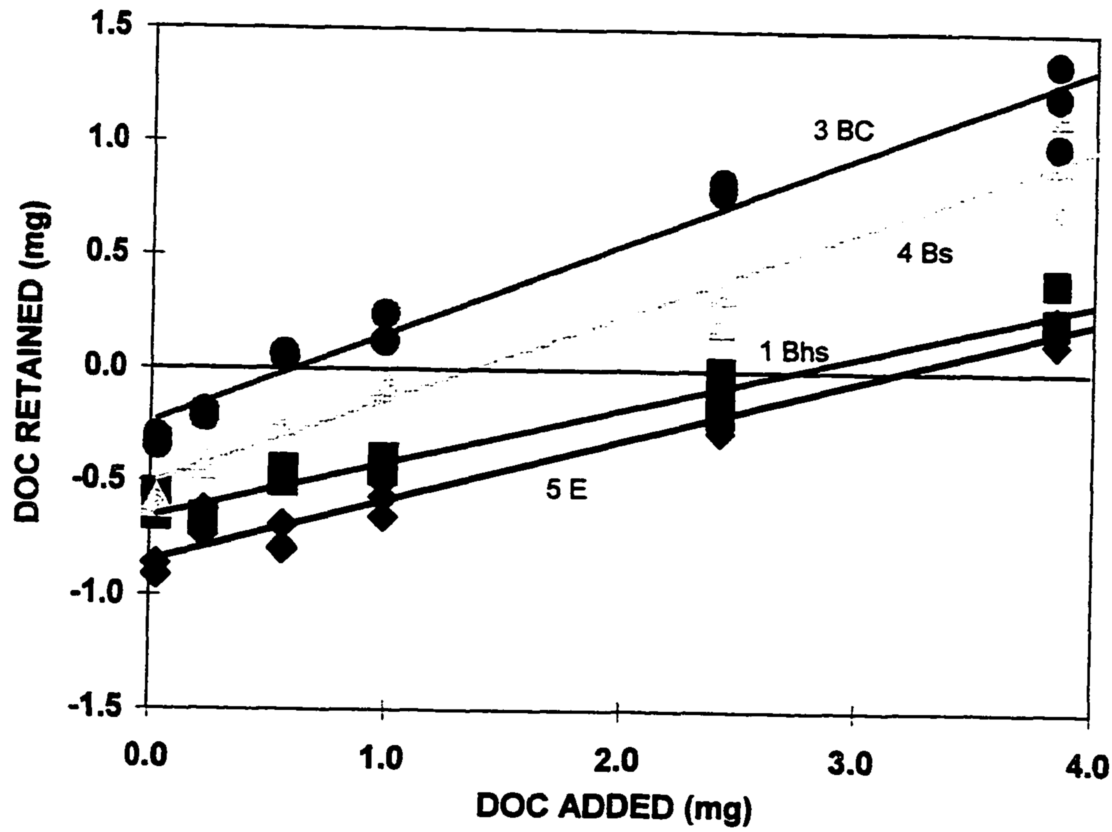



Figure 3-1. Initial mass isotherms of DOC sorption for 4 representative soil horizons from (Berlin field site) Experiment 1. The numbers indicate the site of the horizon isotherm shown. All isotherms were adequately described by linear regression ($p < 0.01$).

Equilibrium DOC concentrations in the soil profile

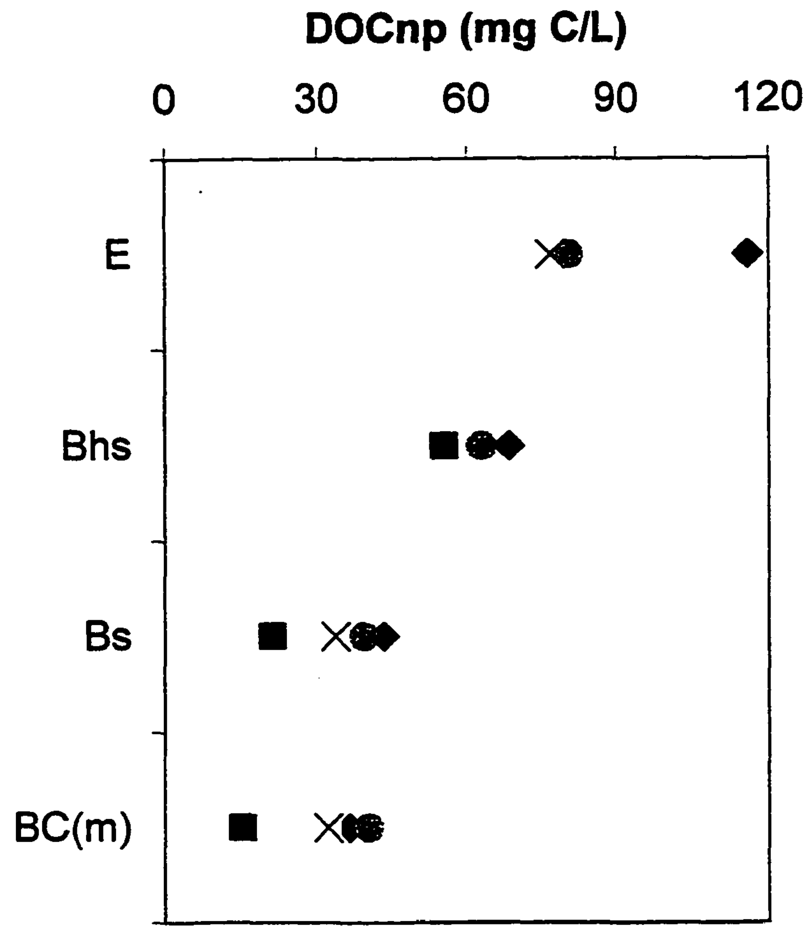



Figure 3-2. Mean equilibrium DOC concentrations (mg/L) by soil horizon for Experiment 1. All horizons from each site have the same symbol on graph -- Site 1 (diamond); Site 3 (square); Site 4 (X) and Site 5 (circle).

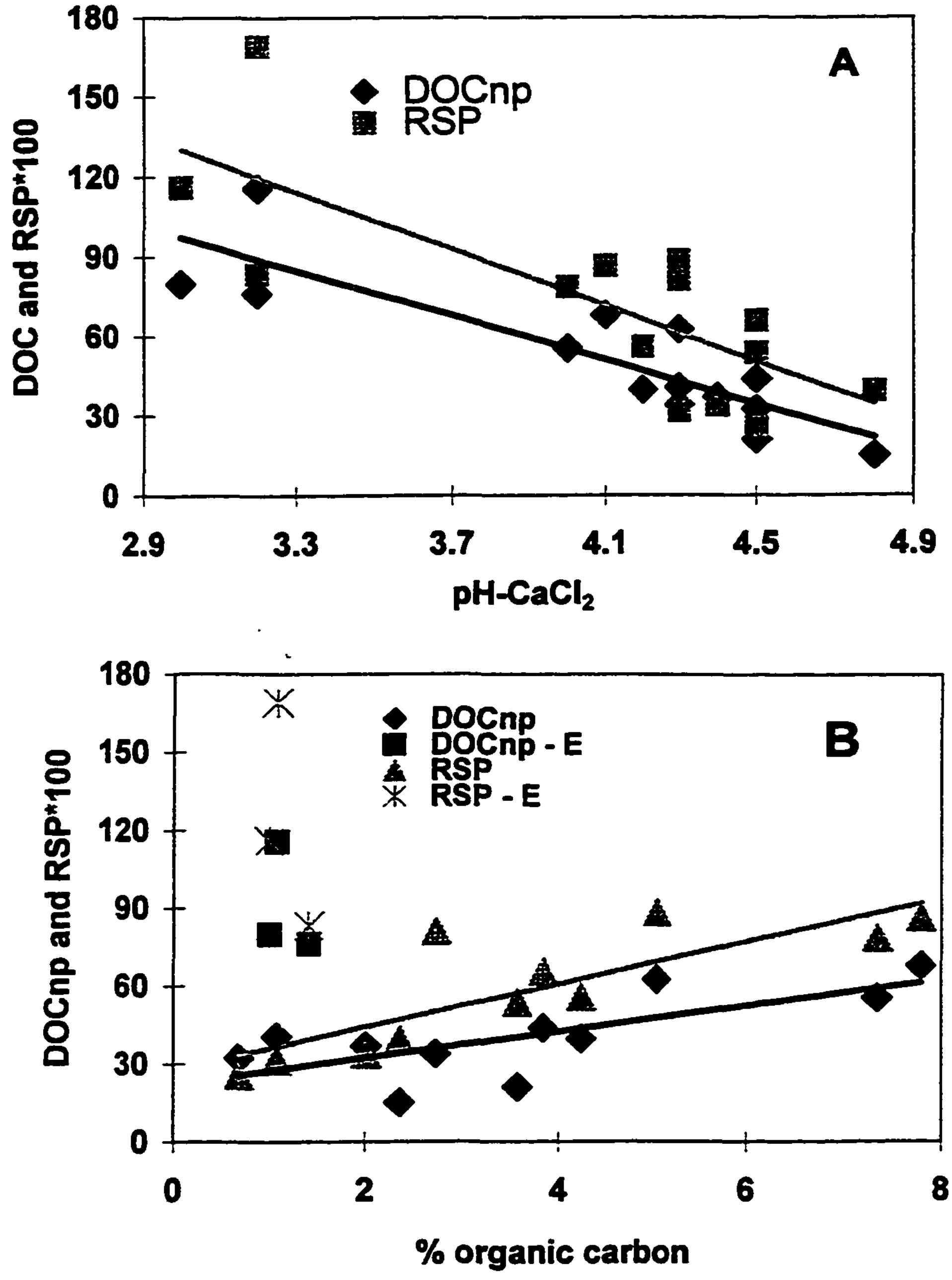



Figure 3-3. Relationships between the $pH_{CaCl2}$ and the equilibrium concentration of DOC and reactive soil pool (RSP) of DOC (A); and the relationships between % organic carbon and the equilibrium concentration of DOC and RSP (B). Values for RSP on both graphs are 100 X greater than actual RSP values.

Relationship between % OC and DOC release from soil horizons

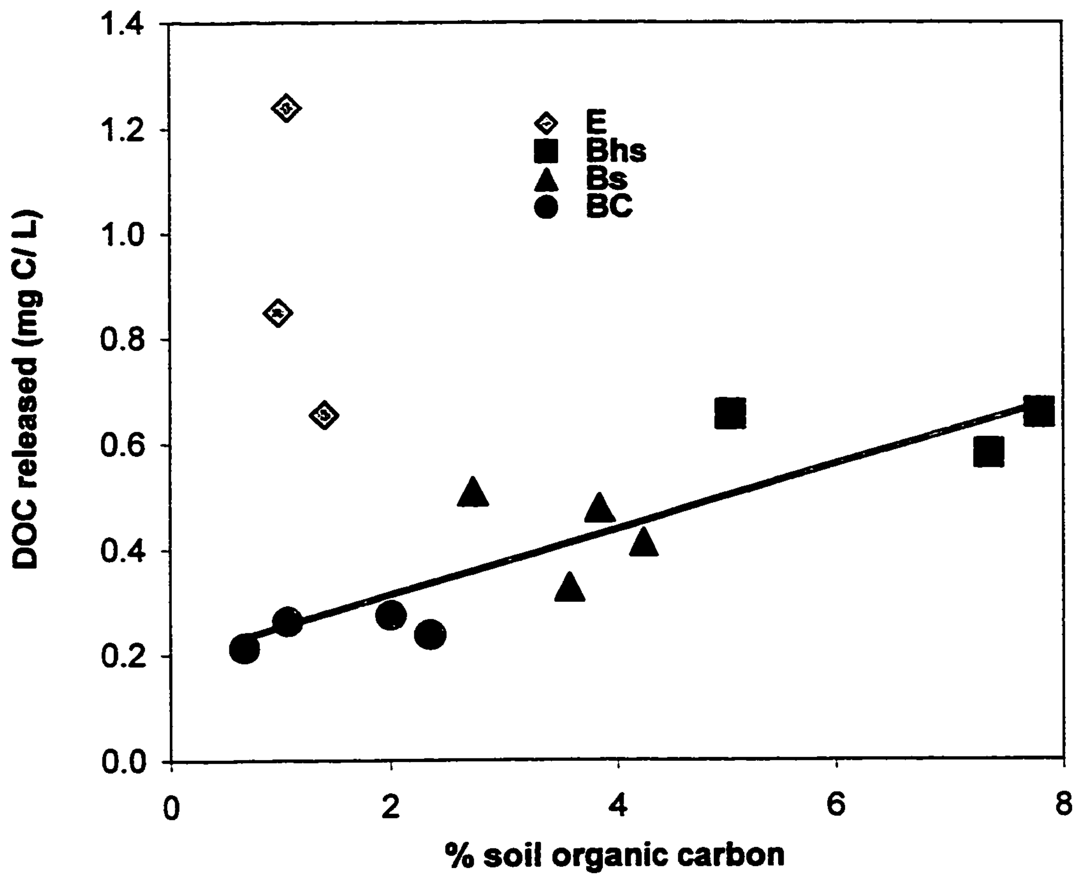
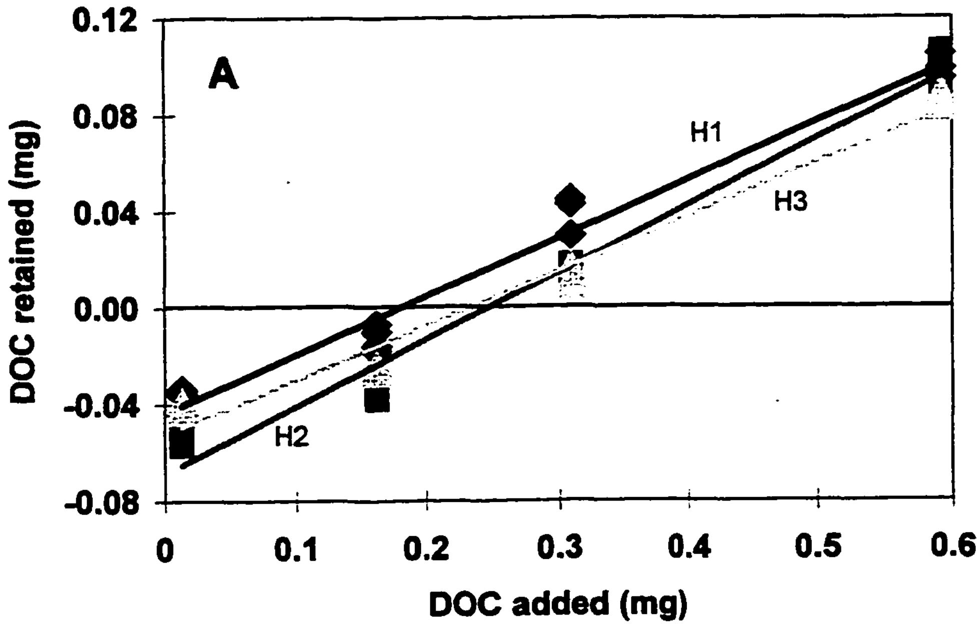



Figure 3-4. The y-intercept, b, was well correlated with the % OC ($r = 0.85$, $p < 0.001$) in Experiment 1 when E horizons were excluded. The term b is equivalent to the amount of DOC released at 0 addition of DOC.

Initial mass isotherms for soil materials from Experiment 2



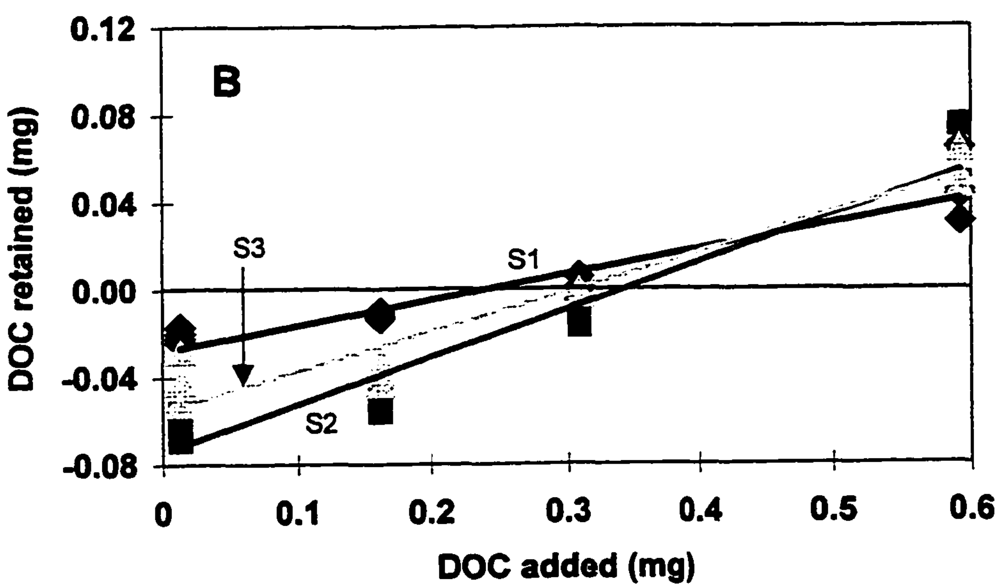




Figure 3-5. Initial mass isotherm of DOC sorption for the Hermon (graph A) and Success soil materials (graph B) used in Experiment 2. The letters indicate the parent material (H = Hermon and S = Success) and the numbers indicate the surface area of the samples. All isotherms were adequately described by linear regression ($p < 0.001$).

Relationship between $DOC_{np}$ and $Fe_d$

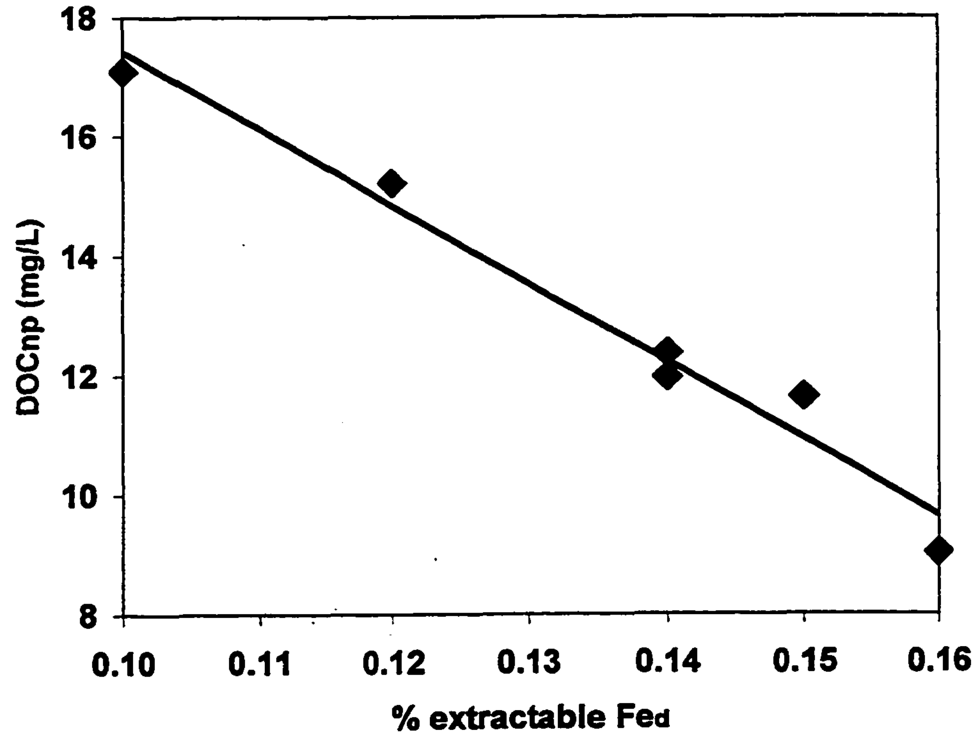



Figure 3-6. The equilibrium concentration of DOC as a function of dithionite extractable Fe content ($Fe_d$ ; $r = -0.98$, $p < 0.01$) in Experiment 2.

## Trends in DOC concentrations in the soil profile

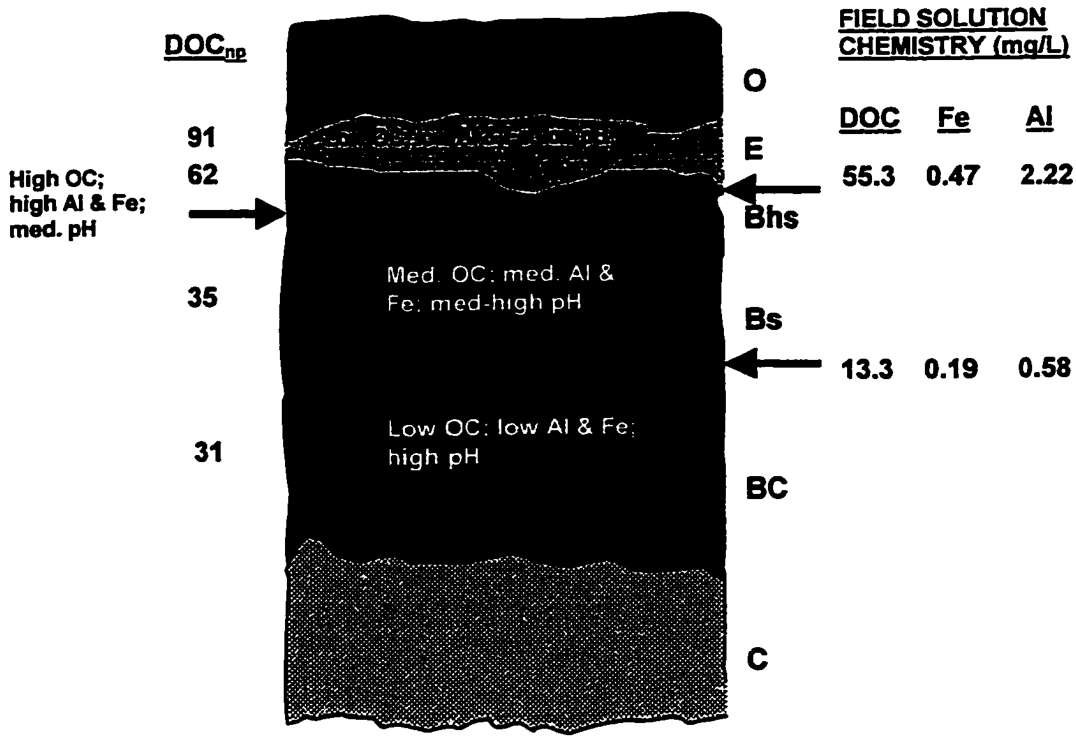



Figure 3-7. Comparison of laboratory derived DOC$_{np}$ values with lysimeter solutions.

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# APPENDIX A: COLUMN STUDY

CHEMICAL COMPOSITION OF THE UNTREATED PARENT MATERIALS USED IN COLUMN STUDIES 1 & 2.
THE 0.053 - 11.2 mm SIZE FRACTION WAS USED. THE < 0.053 mm FRACTION WAS REMOVED BY DRY SIEVING.

| | | HERMON | MARLOW | SUCCESS | LOMBARD |
|---|---|---|---|---|---|
| $SiO_2$ | | 71.5 | 72 | 69.3 | 69.5 |
| weight % | | 71.5 | 71.6 | 68.8 | 69.2 |
| | | 71.3 | 72 | 69.5 | 69.7 |
| | mean | *71.4* | *71.9* | *69.2* | *69.5* |
| | std dev | *0.1* | *0.2* | *0.4* | *0.3* |
| $Al_2O_3$ | | 13.7 | 13.8 | 14.6 | 13.1 |
| weight % | | 13.6 | 13.9 | 14.7 | 13.1 |
| | | 13.7 | 13.9 | 14.5 | 13.1 |
| | mean | *13.7* | *13.9* | *14.6* | *13.1* |
| | std dev | *0.1* | *0.1* | *0.1* | *<0.1* |
| CaO | | 0.58 | 1.53 | 1.46 | 1.99 |
| weight % | | 0.59 | 1.54 | 1.55 | 1.95 |
| | | 0.58 | 1.54 | 1.46 | 1.90 |
| | mean | *0.58* | *1.54* | *1.49* | *1.95* |
| | std dev | *0.01* | *0.01* | *0.05* | *0.05* |
| MgO | | 0.28 | 0.64 | 0.77 | 2.07 |
| weight % | | 0.29 | 0.66 | 0.75 | 2.05 |
| | | 0.28 | 0.65 | 0.76 | 2.07 |
| | mean | *0.28* | *0.65* | *0.76* | *2.06* |
| | std dev | *0.01* | *0.01* | *0.01* | *0.01* |
| $Na_2O$ | | 3.48 | 2.62 | 3.82 | 2.27 |
| weight % | | 3.51 | 2.66 | 3.76 | 2.26 |
| | | 3.49 | 2.65 | 3.85 | 2.27 |
| | mean | *3.49* | *2.64* | *3.81* | *2.27* |
| | std dev | *0.02* | *0.02* | *0.05* | *0.01* |
| $K_2O$ | | 4.96 | 3.56 | 3.92 | 1.72 |
| weight % | | 4.86 | 3.71 | 3.93 | 1.68 |
| | | 4.89 | 3.58 | 3.84 | 1.70 |
| | mean | *4.90* | *3.62* | *3.90* | *1.70* |
| | std dev | *0.05* | *0.08* | *0.05* | *0.02* |
| $Fe_2O_3$ | | 2.60 | 2.43 | 2.35 | 4.06 |
| weight % | | 2.75 | 2.47 | 2.47 | 3.95 |
| | | 2.69 | 2.36 | 2.41 | 4.00 |
| | mean | *2.68* | *2.42* | *2.41* | *4.00* |
| | std dev | *0.08* | *0.06* | *0.06* | *0.06* |
| MnO | | 0.05 | 0.05 | 0.06 | 0.08 |
| weight % | | 0.05 | 0.05 | 0.06 | 0.08 |
| | | 0.05 | 0.05 | 0.06 | 0.08 |
| | mean | *0.05* | *0.05* | *0.06* | *0.08* |
| | std dev | *<0.01* | *<0.01* | *<0.01* | *<0.01* |
| $Cr_2O_3$ | | <0.01 | <0.01 | <0.01 | <0.01 |
| weight % | | <0.01 | <0.01 | <0.01 | <0.01 |
| | | <0.01 | <0.01 | <0.01 | <0.01 |
| $TiO_2$ | | 0.29 | 0.47 | 0.35 | 0.83 |
| weight % | | 0.30 | 0.47 | 0.40 | 0.83 |
| | | 0.31 | 0.47 | 0.35 | 0.84 |
| | mean | *0.30* | *0.47* | *0.37* | *0.83* |
| | std dev | *0.01* | *<0.01* | *0.03* | *0.01* |
| $P_2O_5$ | | 0.08 | 0.21 | 0.10 | 0.14 |
| weight % | | 0.08 | 0.21 | 0.11 | 0.14 |
| | | 0.08 | 0.22 | 0.11 | 0.13 |
| | mean | *0.08* | *0.21* | *0.11* | *0.14* |
| | std dev | *<0.01* | *0.01* | *0.01* | *0.01* |
| Th | | 35 | 17 | 30 | 8.8 |
| ppm | | 34 | 19 | 31 | 9.5 |
| | | 31 | 17 | 31 | 9.2 |
| | mean | *33* | *18* | *31* | *9.2* |
| | std dev | *2.1* | *1.2* | *0.6* | *0.4* |
| U | | 9.4 | 4.3 | 6.3 | 2.0 |
| ppm | | 9.8 | 5.0 | 6.2 | 1.9 |
| | | 9.1 | 4.8 | 7.1 | 2.1 |
| | mean | *9.4* | *4.7* | *6.5* | *2.0* |
| | std dev | *0.4* | *0.4* | *0.5* | *0.1* |

INPUT CONCENTRATIONS OF DOC IN THE FF-HIGH SOLUTION COLUMN STUDY 1. THE CONCENTRATIONS OF DOC IN THE FF-MEDIUM AND FF-LOW INPUT SOLUTIONS ARE 50% AND 10% OF THE FF-HIGH SOLUTIONS, RESPECTIVELY. DATA IN MMOL/L.

| RUN 1 | | RUN 2 | | RUN 3 | | RUN 4 | | RUN 5 | |
|---|---|---|---|---|---|---|---|---|---|
| DAY # | DOC | DAY # | DOC | DAY # | DOC | DAY # | DOC | DAY # | DOC |
| 1 | 14.6 | 73 | 19.3 | 169 | 19.1 | 229 | 45.1 | 286 | 25.7 |
| 4 | 12.3 | 76 | 17.3 | 172 | 34.2 | 232 | 48.4 | 289 | 19.7 |
| 7 | 11.4 | 79 | 17.3 | 175 | 39.0 | 235 | 48.8 | 292 | 23.1 |
| 10 | 8.5 | 82 | 16.3 | 178 | 25.3 | 238 | 21.9 | 295 | 33.1 |
| 13 | 11.1 | 85 | 17.9 | 181 | 44.1 | 241 | 11.9 | 298 | 23.0 |
| 16 | 10.5 | 88 | 14.2 | 184 | 24.6 | 244 | 18.1 | 301 | 18.2 |
| 19 | 10.2 | 91 | 17.2 | 187 | 39.2 | 247 | 12.7 | 304 | 13.6 |
| 22 | 10.5 | 94 | 28.7 | 190 | 38.0 | 250 | 16.9 | 307 | 19.2 |
| 25 | 10.7 | 97 | 17.4 | 193 | 43.4 | 253 | 11.3 | 310 | 26.0 |
| 28 | 10.9 | 100 | 30.3 | 196 | 31.0 | 256 | 17.2 | 313 | 22.6 |
| 31 | 11.7 | 103 | 22.8 | 199 | 45.0 | 259 | 15.7 | 316 | 19.7 |
| 34 | 12.4 | 106 | 25.0 | 202 | 28.8 | 262 | 6.0 | 319 | 19.4 |
| 37 | 7.6 | 109 | 18.1 | 205 | 66.9 | 265 | 8.0 | 322 | 23.8 |
| 40 | 10.3 | 112 | 23.5 | 208 | 26.3 | 268 | 11.0 | 325 | 22.0 |
| 43 | 10.2 | 115 | 8.5 | 211 | 43.8 | 271 | 14.3 | 328 | 33.3 |
| 46 | 10.6 | 118 | 28.0 | 214 | 54.5 | 274 | 13.5 | 331 | 32.2 |
| 49 | 14.2 | 121 | 30.9 | 217 | 63.0 | 277 | 18.4 | 334 | 31.5 |
| 52 | 15.4 | 124 | 29.4 | 220 | 38.7 | 280 | 29.6 | 337 | 28.2 |
| 55 | 13.4 | 127 | 7.9 | 223 | 58.0 | 283 | 23.6 | 340 | 30.1 |
| 58 | 17.5 | 130 | 27.4 | 226 | 45.5 | | | 343 | 17.2 |
| 61 | 9.6 | 133 | 32.6 | | | | | 346 | 26.1 |
| 64 | 16.2 | 136 | 19.1 | | | | | 349 | 25.4 |
| 67 | 12.0 | 139 | 27.2 | | | | | 352 | 19.9 |
| 70 | 18.0 | 142 | 11.5 | | | | | 355 | 24.1 |
| | | 145 | 11.9 | | | | | | |
| | | 148 | 35.7 | | | | | | |
| | | 151 | 31.1 | | | | | | |
| | | 154 | 12.4 | | | | | | |
| | | 157 | 28.7 | | | | | | |
| | | 160 | 10.1 | | | | | | |
| | | 163 | 10.0 | | | | | | |
| | | 166 | 38.5 | | | | | | |

CHEMISTRY OF INPUT SOLUTIONS FOR COLUMN STUDY 1

| ELEMENT | SOLUTION | RUN 1 | RUN 2 | RUN 3 | RUN 4 | RUN 5 |
|---|---|---|---|---|---|---|
| Al | DW | 0.20 | 0.20 | 0.22 | 0.24 | 0.22 |
| μmol/L | HNO3 | 1.04 | 0.93 | 1.04 | 1.00 | 1.10 |
| | FF-LOW | 23.3 | 7.60 | 9.56 | 12.6 | 16.3 |
| | FF-MEDIUM | 30.5 | 37.9 | 47.7 | 62.7 | 81.3 |
| | FF-HIGH | 64.5 | 75.8 | 95.4 | 125 | 163 |
| Ca | DW | 0.25 | 0.21 | 0.22 | 0.28 | 0.29 |
| μmol/L | HNO3 | 1.54 | 1.65 | 1.65 | 1.68 | 1.44 |
| | FF-LOW | 34.3 | 20.0 | 29.8 | 18.4 | 18.6 |
| | FF-MEDIUM | 164 | 99.8 | 149 | 91.9 | 92.9 |
| | FF-HIGH | 327 | 200 | 298 | 184 | 186 |
| Fe | DW | 0.03 | 0.12 | 0.08 | 0.08 | 0.05 |
| μmol/L | HNO3 | 0.31 | 0.24 | 0.15 | 0.24 | 0.28 |
| | FF-LOW | 1.84 | 2.76 | 4.33 | 9.08 | 8.61 |
| | FF-MEDIUM | 8.99 | 13.8 | 21.7 | 45.4 | 43.0 |
| | FF-HIGH | 18.4 | 27.6 | 43.3 | 90.8 | 86.0 |
| Mg | DW | 0.02 | 0.08 | 0.08 | 0.07 | 0.10 |
| μmol/L | HNO3 | 0.26 | 0.29 | 0.21 | 0.28 | 0.33 |
| | FF-LOW | 14.7 | 5.18 | 7.20 | 4.94 | 5.35 |
| | FF-MEDIUM | 74.7 | 25.8 | 36.0 | 24.6 | 26.7 |
| | FF-HIGH | 153 | 51.6 | 72.0 | 49.2 | 53.3 |
| K | DW | 0.02 | 0.05 | 0.03 | 0.08 | 0.01 |
| μmol/L | HNO3 | 0.00 | 0.01 | 0.00 | 0.05 | 0.02 |
| | FF-LOW | 35.2 | 25.4 | 25.3 | 17.0 | 18.1 |
| | FF-MEDIUM | 147 | 127 | 126 | 85.0 | 90.2 |
| | FF-HIGH | 267 | 254 | 253 | 170 | 180 |
| Si | DW | 1.00 | 0.16 | 5.53 | 5.10 | 0.48 |
| μmol/L | HNO3 | 1.30 | 1.30 | 6.45 | 4.86 | 2.92 |
| | FF-LOW | 17.5 | 8.10 | 17.7 | 15.4 | 21.9 |
| | FF-MEDIUM | 76.2 | 40.4 | 88.3 | 77.0 | 109 |
| | FF-HIGH | 151 | 80.7 | 177 | 154 | 219 |
| DOC | FF-LOW | 35.6 | 35.2 | 52.3 | 25.2 | 31.1 |
| mg/L | FF-MEDIUM | 156 | 176 | 261 | 126 | 155 |
| | FF-HIGH | 308 | 352 | 523 | 252 | 311 |

ALUMINUM AND CALCIUM OUTFLOW SOLUTION DATA FOR COLUMN STUDY 1.

| parent material | solution | # | ALUMINUM DATA µmol/L run 1 | run 2 | run 3 | run 4 | run 5 | CALCIUM DATA µmol/L run 1 | run 2 | run 3 | run 4 | run 5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hermon | DW | 1 | 0.22 | 0.33 | 0.19 | 0.30 | 0.44 | 1.45 | 3.84 | 2.35 | 0.60 | 0.85 |
| Hermon | DW | 2 | 0.07 | 0.07 | 0.19 | 0.19 | 0.26 | 1.20 | 3.57 | 1.85 | 0.40 | 0.60 |
| Hermon | DW | 3 | 0.15 | 0.07 | 0.30 | 0.30 | 0.26 | 0.95 | 3.44 | 0.50 | 0.40 | 4.99 |
| | mean | | 0.15 | 0.16 | 0.22 | 0.26 | 0.32 | 1.20 | 3.62 | 1.56 | 0.47 | 2.15 |
| | std dev | | 0.07 | 0.15 | 0.06 | 0.06 | 0.11 | 0.25 | 0.20 | 0.96 | 0.12 | 2.47 |
| Marlow | DW | 1 | 1.22 | 1.04 | 1.78 | 2.08 | 2.19 | 1.27 | 3.84 | 0.65 | 0.60 | 2.62 |
| Marlow | DW | 2 | 2.37 | 1.63 | 2.15 | 2.71 | 3.82 | 1.92 | 3.72 | 0.92 | 4.22 | 0.22 |
| Marlow | DW | 3 | 1.52 | 1.26 | 1.22 | 2.15 | 3.63 | 1.60 | 1.82 | 1.65 | 0.52 | 0.50 |
| | mean | | 1.70 | 1.31 | 1.72 | 2.31 | 3.21 | 1.60 | 3.13 | 1.07 | 1.78 | 1.11 |
| | std dev | | 0.60 | 0.30 | 0.47 | 0.34 | 0.89 | 0.32 | 1.13 | 0.52 | 2.11 | 1.31 |
| Success | DW | 1 | 1.22 | 1.37 | 1.41 | 1.15 | 0.56 | 2.94 | 4.24 | 2.07 | 0.40 | 1.42 |
| Success | DW | 2 | 1.07 | 1.26 | 1.78 | 1.07 | 0.93 | 3.44 | 3.04 | 1.42 | 0.52 | 0.62 |
| Success | DW | 3 | 0.93 | 0.93 | 1.04 | 1.07 | 0.63 | 1.85 | 2.89 | 0.57 | 0.87 | 0.42 |
| | mean | | 1.07 | 1.19 | 1.41 | 1.10 | 0.70 | 2.74 | 3.39 | 1.36 | 0.60 | 0.82 |
| | std dev | | 0.15 | 0.23 | 0.37 | 0.04 | 0.20 | 0.82 | 0.74 | 0.75 | 0.25 | 0.53 |
| Lombard | DW | 1 | 0.63 | 0.19 | 0.19 | 0.33 | 0.26 | 16.7 | 2.77 | 2.84 | 2.12 | 1.20 |
| Lombard | DW | 2 | 0.37 | 0.07 | 0.19 | 0.26 | 0.00 | 3.37 | 2.57 | 3.42 | 1.32 | 0.85 |
| Lombard | DW | 3 | 0.00 | 0.19 | 0.07 | 0.26 | 0.37 | 0.87 | 3.24 | 2.27 | 2.12 | 0.55 |
| | mean | | 0.33 | 0.15 | 0.15 | 0.28 | 0.21 | 6.97 | 2.86 | 2.84 | 1.85 | 0.86 |
| | std dev | | 0.32 | 0.06 | 0.06 | 0.04 | 0.19 | 8.49 | 0.35 | 0.57 | 0.46 | 0.32 |
| Hermon | HNO3 | 1 | 152 | 120 | 136 | 109 | 103 | 8.81 | 14.8 | 14.2 | 13.5 | 11.4 |
| Hermon | HNO3 | 2 | 177 | 123 | 140 | 149 | 139 | 7.86 | 14.3 | 10.9 | 19.4 | 17.7 |
| Hermon | HNO3 | 3 | 127 | 114 | 108 | 129 | 98.2 | 6.74 | 14.2 | 8.01 | 23.3 | 10.4 |
| | mean | | 152 | 119 | 128 | 129 | 114 | 7.80 | 14.5 | 11.0 | 18.8 | 13.2 |
| | std dev | | 25.0 | 4.78 | 17.2 | 27.8 | 22.5 | 1.04 | 0.34 | 3.11 | 4.94 | 3.95 |
| Marlow | HNO3 | 1 | 270 | 235 | 255 | 257 | 191 | 100 | 76.1 | 50.1 | 71.1 | 41.9 |
| Marlow | HNO3 | 2 | 265 | 225 | 242 | 239 | 203 | 89.1 | 70.1 | 52.4 | 67.4 | 40.9 |
| Marlow | HNO3 | 3 | 301 | 242 | 256 | 238 | 232 | 121 | 76.1 | 51.1 | 59.1 | 49.9 |
| | mean | | 279 | 234 | 251 | 245 | 208 | 103 | 74.1 | 51.2 | 65.9 | 44.2 |
| | std dev | | 19.7 | 8.42 | 8.14 | 10.8 | 21.1 | 16.0 | 3.46 | 1.13 | 6.13 | 4.92 |
| Success | HNO3 | 1 | 280 | 225 | 218 | 207 | 207 | 70.6 | 60.9 | 38.9 | 54.9 | 36.9 |
| Success | HNO3 | 2 | 238 | 208 | 216 | 208 | 200 | 49.7 | 52.9 | 42.2 | 62.9 | 44.4 |
| Success | HNO3 | 3 | 241 | 185 | 195 | 187 | 168 | 63.1 | 45.7 | 39.2 | 55.9 | 36.7 |
| | mean | | 253 | 206 | 210 | 201 | 191 | 61.1 | 53.1 | 40.1 | 57.9 | 39.3 |
| | std dev | | 23.6 | 20.3 | 12.7 | 12.1 | 21.0 | 10.6 | 7.61 | 1.80 | 4.35 | 4.40 |

| parent material | solution | # | ALUMINUM DATA µmol/L run 1 | run 2 | run 3 | run 4 | run 5 | CALCIUM DATA µmol/L run 1 | run 2 | run 3 | run 4 | run 5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lombard | HNO3 | 1 | 5.23 | 6.67 | 9.71 | 17.9 | 24.8 | 407 | 347 | 319 | 292 | 213 |
| Lombard | HNO3 | 2 | 4.23 | 5.71 | 8.56 | 12.5 | 17.5 | 269 | 269 | 254 | 222 | 192 |
| Lombard | HNO3 | 3 | 5.11 | 6.04 | 9.53 | 14.2 | 18.8 | 329 | 264 | 262 | 257 | 153 |
| | mean | | 4.86 | 6.14 | 9.27 | 14.9 | 20.4 | 335 | 294 | 279 | 257 | 186 |
| | std dev | | 0.55 | 0.49 | 0.62 | 2.78 | 3.90 | 68.8 | 46.2 | 35.5 | 34.8 | 30.5 |
| Hermon | FF-LOW | 1 | 27.1 | 17.3 | 31.7 | 26.1 | 31.8 | 50.4 | 24.1 | 40.7 | 24.6 | 23.1 |
| Hermon | FF-LOW | 2 | 10.7 | 20.5 | 51.5 | 39.3 | 38.5 | 31.9 | 27.4 | 37.4 | 22.0 | 22.7 |
| Hermon | FF-LOW | 3 | 12.1 | 25.2 | 58.6 | 38.2 | 43.4 | 31.4 | 26.7 | 38.4 | 21.5 | 25.9 |
| | mean | | 16.6 | 21.0 | 47.3 | 34.5 | 37.9 | 37.9 | 26.1 | 38.8 | 22.7 | 23.9 |
| | std dev | | 9.05 | 3.93 | 13.9 | 7.34 | 5.79 | 10.8 | 1.74 | 1.66 | 1.67 | 1.78 |
| Marlow | FF-LOW | 1 | 18.0 | 29.2 | 43.4 | 39.3 | 39.7 | 32.4 | 27.4 | 28.4 | 16.2 | 31.7 |
| Marlow | FF-LOW | 2 | 14.8 | 30.9 | 47.8 | 35.2 | 41.1 | 27.9 | 29.9 | 33.4 | 18.6 | 25.7 |
| Marlow | FF-LOW | 3 | 15.7 | 27.4 | 41.5 | 30.5 | 35.2 | 29.7 | 24.4 | 36.2 | 21.2 | 24.8 |
| | mean | | 16.1 | 29.2 | 44.2 | 35.0 | 38.7 | 30.0 | 27.3 | 32.7 | 18.7 | 27.4 |
| | std dev | | 1.66 | 1.80 | 3.24 | 4.39 | 3.09 | 2.26 | 2.79 | 3.92 | 2.51 | 3.76 |
| Success | FF-LOW | 1 | 17.4 | 30.9 | 53.4 | 36.2 | 42.6 | 36.2 | 29.4 | 48.7 | 24.1 | 27.2 |
| Success | FF-LOW | 2 | 16.2 | 27.8 | 51.9 | 37.8 | 43.4 | 34.4 | 29.2 | 39.2 | 20.8 | 26.4 |
| Success | FF-LOW | 3 | 19.0 | 30.8 | 49.3 | 30.7 | 35.7 | 33.4 | 26.4 | 37.4 | 20.0 | 26.4 |
| | mean | | 17.6 | 29.8 | 51.5 | 34.9 | 40.6 | 34.7 | 28.4 | 41.7 | 21.6 | 26.7 |
| | std dev | | 1.39 | 1.75 | 2.06 | 3.76 | 4.23 | 1.39 | 1.66 | 6.04 | 2.19 | 0.43 |
| Lombard | FF-LOW | 1 | 6.37 | 9.60 | 15.3 | 14.7 | 19.8 | 58.6 | 66.1 | 139 | 85.3 | 106 |
| Lombard | FF-LOW | 2 | 5.37 | 8.78 | 14.2 | 13.8 | 17.6 | 50.1 | 72.4 | 131 | 75.1 | 97.6 |
| Lombard | FF-LOW | 3 | 5.04 | 8.26 | 11.7 | 12.7 | 16.0 | 48.9 | 62.4 | 102 | 66.4 | 81.1 |
| | mean | | 5.60 | 8.88 | 13.7 | 13.8 | 17.8 | 52.6 | 66.9 | 124.0 | 75.6 | 94.9 |
| | std dev | | 0.69 | 0.67 | 1.87 | 0.98 | 1.91 | 5.29 | 5.04 | 19.2 | 9.49 | 12.7 |
| Hermon | FF-MED | 1 | 44.5 | 92.7 | 202 | 143 | 175 | 161 | 122 | 170 | 114 | 145 |
| Hermon | FF-MED | 2 | 49.7 | 86.4 | 201 | 145 | 183 | 156 | 123 | 180 | 93.8 | 123 |
| Hermon | FF-MED | 3 | 47.8 | 120 | 214 | 143 | 167 | 152 | 120 | 198 | 110 | 110 |
| | mean | | 47.3 | 99.7 | 206 | 143 | 175 | 156 | 122 | 183 | 106 | 126 |
| | std dev | | 2.63 | 17.9 | 7.17 | 0.98 | 7.97 | 4.62 | 1.60 | 14.2 | 10.5 | 18.1 |
| Marlow | FF-MED | 1 | 84.9 | 159 | 221 | 161 | 246 | 160 | 135 | 175 | 107 | 159 |
| Marlow | FF-MED | 2 | 73.4 | 178 | 206 | 157 | 189 | 146 | 116 | 162 | 133 | 135 |
| Marlow | FF-MED | 3 | 73.8 | 157 | 212 | 154 | 196 | 149 | 117 | 157 | 134 | 141 |
| | mean | | 77.3 | 165 | 213 | 157 | 210 | 152 | 123 | 164 | 125 | 145 |
| | std dev | | 6.53 | 11.9 | 7.44 | 3.36 | 31.2 | 7.73 | 10.8 | 9.24 | 15.3 | 12.3 |

| parent material | solution | # | ALUMINUM DATA µmol/L run 1 | run 2 | run 3 | run 4 | run 5 | CALCIUM DATA µmol/L run 1 | run 2 | run 3 | run 4 | run 5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Success | FF-MED | 1 | 61.9 | 99.3 | 426 | 111 | 142 | 163 | 129 | 160 | 92.8 | 122 |
| Success | FF-MED | 2 | 67.5 | 103 | 186 | 123 | 146 | 152 | 117 | 153 | 114 | 118 |
| Success | FF-MED | 3 | 68.2 | 97.5 | 136 | 112 | 132 | 157 | 123 | 160 | 101 | 119 |
| | mean | | 65.8 | 100 | 249 | 115 | 140 | 157 | 123 | 158 | 102 | 120 |
| | std dev | | 3.44 | 3.03 | 155 | 6.43 | 7.20 | 5.40 | 5.99 | 3.90 | 10.7 | 2.04 |
| Lombard | FF-MED | 1 | 33.8 | 58.6 | 99.0 | 83.8 | 281 | 254 | 289 | 412 | 204 | 296 |
| Lombard | FF-MED | 2 | 34.7 | 54.9 | 96.4 | 79.7 | 91.2 | 247 | 287 | 434 | 185 | 252 |
| Lombard | FF-MED | 3 | 31.1 | 58.9 | 104 | 82.0 | 94.5 | 254 | 279 | 422 | 195 | 272 |
| | mean | | 33.2 | 57.4 | 99.7 | 81.7 | 156 | 252 | 285 | 422 | 194 | 273 |
| | std dev | | 1.85 | 2.25 | 3.76 | 2.88 | 109 | 4.32 | 5.19 | 11.3 | 12.9 | 21.9 |
| Hermon | FF-HIGH | 1 | 145 | 280 | 361 | 248 | 288 | 342 | 247 | 399 | 204 | 222 |
| Hermon | FF-HIGH | 2 | 123 | 236 | 357 | 247 | 311 | 319 | 234 | 312 | 208 | 233 |
| Hermon | FF-HIGH | 3 | 126 | 206 | 393 | 245 | 294 | 319 | 224 | 317 | 213 | 232 |
| | mean | | 131 | 241 | 370 | 247 | 297 | 327 | 235 | 343 | 208 | 229 |
| | std dev | | 12.0 | 37.3 | 19.8 | 2.10 | 11.8 | 13.0 | 11.6 | 49.0 | 5.82 | 6.30 |
| Marlow | FF-HIGH | 1 | 202 | 385 | 478 | 325 | 385 | 327 | 262 | 369 | 329 | 279 |
| Marlow | FF-HIGH | 2 | 160 | 222 | 415 | 284 | 397 | 332 | 225 | 299 | 269 | 250 |
| Marlow | FF-HIGH | 3 | 139 | 189 | 270 | 216 | 277 | 337 | 234 | 324 | 233 | 230 |
| | mean | | 167 | 265 | 388 | 275 | 353 | 332 | 240 | 331 | 277 | 253 |
| | std dev | | 32.1 | 105 | 107 | 54.9 | 65.9 | 4.99 | 19.5 | 35.4 | 48.6 | 25.0 |
| Success | FF-HIGH | 1 | 136 | 328 | 434 | 311 | 348 | 337 | 254 | 362 | 264 | 235 |
| Success | FF-HIGH | 2 | 132 | 224 | 397 | 295 | 322 | 337 | 233 | 334 | 254 | 216 |
| Success | FF-HIGH | 3 | 136 | 212 | 378 | 238 | 301 | 324 | 222 | 312 | 218 | 224 |
| | mean | | 135 | 255 | 403 | 281 | 324 | 333 | 237 | 336 | 246 | 225 |
| | std dev | | 2.47 | 63.4 | 28.3 | 38.3 | 23.4 | 7.20 | 16.5 | 25.0 | 24.7 | 9.62 |
| Lombard | FF-HIGH | 1 | 79.3 | 190 | 265 | 157 | 183 | 482 | 479 | 594 | 362 | 392 |
| Lombard | FF-HIGH | 2 | 80.8 | 171 | 213 | 161 | 188 | 497 | 511 | 601 | 317 | 322 |
| Lombard | FF-HIGH | 3 | 67.5 | 119 | 207 | 166 | 187 | 417 | 427 | 559 | 329 | 364 |
| | mean | | 75.9 | 160 | 228 | 161 | 186 | 465 | 472 | 585 | 336 | 359 |
| | std dev | | 7.31 | 36.7 | 32.1 | 4.45 | 2.81 | 42.4 | 42.8 | 22.6 | 23.2 | 35.2 |

DOC OUTFLOW SOLUTION DATA FOR COLUMN STUDY 1.

| parent material | solution | # | run 1 | run 2 | run 3 | run 4 | run 5 |
|---|---|---|---|---|---|---|---|
| | | | | | DOC DATA mg/L | | |
| Hermon | FF-LOW | 1 | 35.0 | 25.6 | 35.6 | 22.9 | 12.9 |
| Hermon | FF-LOW | 2 | 33.1 | 26.7 | 32.0 | 21.7 | 18.3 |
| Hermon | FF-LOW | 3 | 29.7 | 24.9 | 29.4 | 21.7 | 17.8 |
| | mean | | 32.6 | 25.7 | 32.3 | 22.1 | 16.3 |
| | std dev | | 2.69 | 0.91 | 3.11 | 0.72 | 2.98 |
| Marlow | FF-LOW | 1 | 27.8 | 26.7 | 40.1 | 27.1 | 19.1 |
| Marlow | FF-LOW | 2 | 26.2 | 25.8 | 34.9 | 26.8 | 15.3 |
| Marlow | FF-LOW | 3 | 28.3 | 26.4 | 38.1 | 25.7 | 14.4 |
| | mean | | 27.4 | 26.3 | 37.7 | 26.5 | 16.3 |
| | std dev | | 1.10 | 0.46 | 2.62 | 0.77 | 2.49 |
| Success | FF-LOW | 1 | 34.9 | 32.8 | 41.1 | 26.3 | 19.3 |
| Success | FF-LOW | 2 | 33.6 | 31.4 | 37.9 | 25.2 | 19.1 |
| Success | FF-LOW | 3 | 31.6 | 27.8 | 40.5 | 26.6 | 16.7 |
| | mean | | 33.4 | 30.7 | 39.8 | 26.0 | 18.4 |
| | std dev | | 1.66 | 2.58 | 1.70 | 0.74 | 1.45 |
| Lombard | FF-LOW | 1 | 36.1 | 32.6 | 45.8 | 26.7 | 21.8 |
| Lombard | FF-LOW | 2 | 33.1 | 31.8 | 41.8 | 26.3 | 16.7 |
| Lombard | FF-LOW | 3 | 33.3 | 33.6 | 43.7 | 26.4 | 16.6 |
| | mean | | 34.2 | 32.7 | 43.8 | 26.5 | 18.4 |
| | std dev | | 1.68 | 0.90 | 2.00 | 0.21 | 2.97 |
| Hermon | FF-MEDIUM | 1 | 149 | 132 | 248 | 107 | 141 |
| Hermon | FF-MEDIUM | 2 | 146 | 139 | 212 | 109 | 152 |
| Hermon | FF-MEDIUM | 3 | 144 | 141 | 201 | 99.3 | 135 |
| | mean | | 146 | 137 | 220 | 105 | 142 |
| | std dev | | 2.60 | 4.79 | 24.4 | 5.23 | 8.60 |
| Marlow | FF-MEDIUM | 1 | 130 | 133 | 217 | 111 | 114 |
| Marlow | FF-MEDIUM | 2 | 125 | 145 | 219 | 92.1 | 91.3 |
| Marlow | FF-MEDIUM | 3 | 126 | 145 | 222 | 95.5 | 102 |
| | mean | | 127 | 141 | 219 | 100 | 102 |
| | std dev | | 2.91 | 6.87 | 2.80 | 10.3 | 11.1 |

| parent material | solution | # | DOC DATA mg/L run 1 | run 2 | run 3 | run 4 | run 5 |
|---|---|---|---|---|---|---|---|
| Success | FF-MEDIUM | 1 | 147 | 156 | 244 | 119 | 139 |
| Success | FF-MEDIUM | 2 | 137 | 148 | 248 | 109 | 141 |
| Success | FF-MEDIUM | 3 | 138 | 156 | 253 | 113 | 136 |
| | mean | | 141 | 153 | 248 | 114 | 139 |
| | std dev | | 5.12 | 4.82 | 4.05 | 5.12 | 2.57 |
| Lombard | FF-MEDIUM | 1 | 150 | 164 | 246 | 116 | 139 |
| Lombard | FF-MEDIUM | 2 | 141 | 162 | 236 | 113 | 131 |
| Lombard | FF-MEDIUM | 3 | 145 | 165 | 240 | 113 | 142 |
| | mean | | 145 | 163 | 241 | 114 | 137 |
| | std dev | | 4.81 | 1.64 | 4.86 | 1.85 | 5.67 |
| Hermon | FF-HIGH | 1 | 287 | 348 | 502 | 232 | 320 |
| Hermon | FF-HIGH | 2 | 286 | 329 | 501 | 233 | 286 |
| Hermon | FF-HIGH | 3 | 278 | 327 | 499 | 238 | 296 |
| | mean | | 284 | 335 | 500 | 234 | 300 |
| | std dev | | 4.65 | 11.8 | 1.31 | 3.30 | 17.2 |
| Marlow | FF-HIGH | 1 | 244 | 330 | 487 | 228 | 284 |
| Marlow | FF-HIGH | 2 | 272 | 338 | 485 | 204 | 250 |
| Marlow | FF-HIGH | 3 | 285 | 341 | 497 | 219 | 272 |
| | mean | | 267 | 336 | 490 | 217 | 268 |
| | std dev | | 21.0 | 5.78 | 6.73 | 12.0 | 17.3 |
| Success | FF-HIGH | 1 | 283 | 376 | 533 | 218 | 319 |
| Success | FF-HIGH | 2 | 283 | 352 | 503 | 232 | 327 |
| Success | FF-HIGH | 3 | 278 | 348 | 497 | 237 | 306 |
| | mean | | 281 | 359 | 511 | 229 | 317 |
| | std dev | | 2.77 | 14.8 | 19.5 | 9.85 | 10.7 |
| Lombard | FF-HIGH | 1 | 279 | 316 | 438 | 213 | 290 |
| Lombard | FF-HIGH | 2 | 252 | 307 | 415 | 206 | 282 |
| Lombard | FF-HIGH | 3 | 268 | 319 | 461 | 216 | 273 |
| | mean | | 266 | 314 | 438 | 212 | 281 |
| | std dev | | 13.2 | 6.31 | 23.2 | 5.01 | 12.5 |

IRON AND MAGNESIUM OUTFLOW SOLUTION DATA FOR COLUMN STUDY 1.

| | | | IRON DATA µmol/L | | | | | MAGNESIUM DATA µmol/L | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| parent material | solution | # | run 1 | run 2 | run 3 | run 4 | run 5 | run 1 | run 2 | run 3 | run 4 | run 5 |
| Hermon | DW | 1 | 0.16 | 0.07 | 0.11 | -0.20 | 0.09 | 0.41 | 1.11 | 0.45 | 0.21 | 0.29 |
| Hermon | DW | 2 | 0.13 | 0.07 | -0.04 | -0.11 | -0.16 | 0.37 | 0.78 | 0.33 | 0.12 | 0.16 |
| Hermon | DW | 3 | 0.04 | -0.20 | -0.14 | -0.27 | -0.16 | 0.33 | 1.03 | 0.21 | 0.08 | 2.92 |
| | mean | | 0.11 | -0.02 | -0.02 | -0.19 | -0.08 | 0.37 | 0.97 | 0.33 | 0.14 | 1.12 |
| | std dev | | 0.06 | 0.16 | 0.13 | 0.08 | 0.14 | 0.04 | 0.17 | 0.12 | 0.06 | 1.56 |
| Marlow | DW | 1 | 0.13 | 0.07 | -0.43 | -0.13 | 0.20 | 0.25 | 1.03 | 0.16 | 0.21 | 0.82 |
| Marlow | DW | 2 | 0.09 | 0.00 | -0.11 | 0.04 | 1.40 | 0.37 | 0.99 | 0.25 | 1.48 | 0.25 |
| Marlow | DW | 3 | 0.09 | -0.04 | -0.21 | -0.11 | 0.82 | 0.37 | 0.37 | 1.97 | 0.25 | 0.29 |
| | mean | | 0.10 | 0.01 | -0.25 | -0.07 | 0.81 | 0.33 | 0.80 | 0.80 | 0.64 | 0.45 |
| | std dev | | 0.02 | 0.05 | 0.16 | 0.09 | 0.60 | 0.07 | 0.37 | 1.02 | 0.72 | 0.32 |
| Success | DW | 1 | 0.16 | 0.07 | -0.07 | 0.04 | 0.04 | 0.53 | 1.11 | 0.49 | 0.00 | 0.21 |
| Success | DW | 2 | 0.04 | -0.04 | -0.11 | -0.07 | -0.20 | 1.23 | 0.86 | 0.33 | 0.00 | 0.12 |
| Success | DW | 3 | 0.00 | 0.20 | -0.18 | -0.14 | -0.43 | 0.33 | 0.82 | 0.12 | 0.00 | -0.08 |
| | mean | | 0.07 | 0.08 | -0.12 | -0.06 | -0.20 | 0.70 | 0.93 | 0.32 | 0.00 | 0.08 |
| | std dev | | 0.08 | 0.12 | 0.05 | 0.09 | 0.23 | 0.47 | 0.16 | 0.19 | >0.01 | 0.15 |
| Lombard | DW | 1 | 0.00 | 0.04 | 0.04 | 0.18 | 0.27 | 2.55 | 0.95 | 1.03 | 0.45 | 0.33 |
| Lombard | DW | 2 | 0.13 | 0.27 | -0.04 | 0.21 | -0.23 | 0.82 | 0.86 | 1.19 | 0.37 | 0.21 |
| Lombard | DW | 3 | 0.32 | 0.34 | -0.23 | 0.32 | 0.04 | 0.41 | 1.07 | 0.78 | 0.45 | 0.25 |
| | mean | | 0.15 | 0.21 | -0.08 | 0.24 | 0.02 | 1.26 | 0.96 | 1.00 | 0.43 | 0.26 |
| | std dev | | 0.16 | 0.16 | 0.14 | 0.07 | 0.25 | 1.13 | 0.10 | 0.21 | 0.05 | 0.06 |
| Hermon | HNO3 | 1 | 0.45 | 0.81 | 0.48 | 0.54 | 0.34 | 0.49 | 1.28 | 1.32 | 0.45 | 0.86 |
| Hermon | HNO3 | 2 | 0.57 | 0.88 | 0.16 | 0.47 | 0.66 | 0.37 | 1.15 | 0.70 | 0.58 | 1.07 |
| Hermon | HNO3 | 3 | 0.45 | 0.77 | 0.13 | 0.51 | 1.16 | 0.37 | 1.56 | 0.53 | 5.06 | 0.78 |
| | mean | | 0.49 | 0.82 | 0.26 | 0.50 | 0.72 | 0.41 | 1.33 | 0.85 | 2.03 | 0.90 |
| | std dev | | 0.07 | 0.05 | 0.20 | 0.05 | 0.42 | 0.07 | 0.21 | 0.41 | 2.62 | 0.15 |
| Marlow | HNO3 | 1 | 0.45 | 0.23 | 0.27 | 0.39 | 1.40 | 1.03 | 2.06 | 1.89 | 2.22 | 2.92 |
| Marlow | HNO3 | 2 | 0.56 | 0.23 | 0.23 | 0.18 | 1.27 | 1.23 | 0.95 | 1.69 | 1.73 | 2.34 |
| Marlow | HNO3 | 3 | 0.63 | 0.66 | 0.43 | 0.43 | 1.07 | 1.03 | 1.48 | 2.02 | 1.85 | 2.76 |
| | mean | | 0.54 | 0.38 | 0.31 | 0.33 | 1.25 | 1.10 | 1.49 | 1.86 | 1.93 | 2.67 |
| | std dev | | 0.09 | 0.25 | 0.10 | 0.14 | 0.16 | 0.12 | 0.56 | 0.17 | 0.26 | 0.30 |
| Success | HNO3 | 1 | 0.47 | 0.63 | 0.20 | 0.47 | 1.07 | 1.28 | 1.56 | 24.7 | 2.39 | 3.33 |
| Success | HNO3 | 2 | 0.50 | 0.63 | 0.16 | 0.64 | 1.20 | 1.52 | 1.89 | 2.39 | 2.34 | 2.88 |
| Success | HNO3 | 3 | 0.63 | 0.52 | 0.34 | 0.43 | 0.43 | 3.25 | 1.28 | 2.06 | 2.02 | 2.30 |
| | mean | | 0.53 | 0.59 | 0.23 | 0.51 | 0.90 | 2.02 | 1.58 | 9.71 | 2.25 | 2.84 |
| | std dev | | 0.08 | 0.06 | 0.09 | 0.12 | 0.41 | 1.08 | 0.31 | 13.0 | 0.20 | 0.52 |

| | | | IRON DATA µmol/L | | | | | MAGNESIUM DATA µmol/L | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| parent material | solution | # | run 1 | run 2 | run 3 | run 4 | run 5 | run 1 | run 2 | run 3 | run 4 | run 5 |
| Lombard | HNO3 | 1 | 0.23 | 0.29 | 0.04 | 0.14 | 0.64 | 127 | 113 | 113 | 115 | 92.5 |
| Lombard | HNO3 | 2 | 0.20 | 0.52 | 0.18 | 0.70 | 0.43 | 77.3 | 85.1 | 88.4 | 81.4 | 77.7 |
| Lombard | HNO3 | 3 | 0.23 | 0.32 | 0.27 | 0.39 | 0.04 | 97.1 | 86.0 | 97.9 | 98.7 | 63.8 |
| | mean | | 0.22 | 0.38 | 0.16 | 0.41 | 0.37 | 100 | 94.7 | 99.8 | 98.3 | 78.0 |
| | std dev | | 0.02 | 0.13 | 0.12 | 0.28 | 0.31 | 25.1 | 15.9 | 12.5 | 16.7 | 14.4 |
| Hermon | FF-LOW | 1 | 1.61 | 2.83 | 4.12 | 6.16 | 5.09 | 17.9 | 6.54 | 9.42 | 6.09 | 6.25 |
| Hermon | FF-LOW | 2 | 1.40 | 1.97 | 2.92 | 3.28 | 3.31 | 12.6 | 7.12 | 8.47 | 5.39 | 5.96 |
| Hermon | FF-LOW | 3 | 0.90 | 1.67 | 2.70 | 2.95 | 3.24 | 11.4 | 6.38 | 8.60 | 5.26 | 6.79 |
| | mean | | 1.30 | 2.15 | 3.25 | 4.13 | 3.88 | 14.0 | 6.68 | 8.83 | 5.58 | 6.33 |
| | std dev | | 0.37 | 0.60 | 0.76 | 1.76 | 1.04 | 3.47 | 0.39 | 0.51 | 0.44 | 0.42 |
| Marlow | FF-LOW | 1 | 0.86 | 2.02 | 3.10 | 3.94 | 3.60 | 12.5 | 6.95 | 7.24 | 4.77 | 8.64 |
| Marlow | FF-LOW | 2 | 0.27 | 2.02 | 2.54 | 2.81 | 2.69 | 10.0 | 7.77 | 7.98 | 4.89 | 6.79 |
| Marlow | FF-LOW | 3 | 0.70 | 1.59 | 3.13 | 3.04 | 3.56 | 11.3 | 6.01 | 8.27 | 5.22 | 6.50 |
| | mean | | 0.61 | 1.88 | 2.92 | 3.26 | 3.28 | 11.3 | 6.91 | 7.83 | 4.96 | 7.31 |
| | std dev | | 0.31 | 0.25 | 0.33 | 0.60 | 0.52 | 1.30 | 0.89 | 0.53 | 0.23 | 1.16 |
| Success | FF-LOW | 1 | 0.86 | 2.13 | 3.40 | 3.90 | 4.08 | 13.4 | 7.49 | 11.0 | 6.09 | 7.49 |
| Success | FF-LOW | 2 | 1.02 | 2.31 | 2.97 | 4.12 | 4.17 | 12.8 | 7.24 | 8.60 | 5.47 | 7.90 |
| Success | FF-LOW | 3 | 1.06 | 2.20 | 2.97 | 4.26 | 4.58 | 11.9 | 6.87 | 8.51 | 5.14 | 7.61 |
| | mean | | 0.98 | 2.21 | 3.12 | 4.09 | 4.28 | 12.7 | 7.20 | 9.36 | 5.57 | 7.66 |
| | std dev | | 0.10 | 0.09 | 0.25 | 0.18 | 0.27 | 0.76 | 0.31 | 1.40 | 0.48 | 0.21 |
| Lombard | FF-LOW | 1 | 1.75 | 3.29 | 5.17 | 5.62 | 7.05 | 16.9 | 18.4 | 40.1 | 26.3 | 34.0 |
| Lombard | FF-LOW | 2 | 1.22 | 2.45 | 5.37 | 5.50 | 5.82 | 14.6 | 21.0 | 37.3 | 23.1 | 29.9 |
| Lombard | FF-LOW | 3 | 1.29 | 2.69 | 4.42 | 5.09 | 5.14 | 14.1 | 17.5 | 28.8 | 20.2 | 25.0 |
| | mean | | 1.42 | 2.81 | 4.99 | 5.40 | 6.00 | 15.2 | 18.9 | 35.4 | 23.2 | 29.6 |
| | std dev | | 0.29 | 0.43 | 0.50 | 0.28 | 0.97 | 1.49 | 1.81 | 5.85 | 3.09 | 4.47 |
| Hermon | FF-MED | 1 | 7.72 | 12.8 | 22.6 | 30.6 | 39.8 | 67.5 | 31.3 | 39.1 | 31.1 | 41.5 |
| Hermon | FF-MED | 2 | 6.93 | 11.3 | 19.0 | 29.9 | 41.9 | 62.9 | 32.3 | 42.0 | 24.7 | 35.5 |
| Hermon | FF-MED | 3 | 7.31 | 13.3 | 22.6 | 28.3 | 39.8 | 61.7 | 31.1 | 46.9 | 28.5 | 31.1 |
| | mean | | 7.32 | 12.5 | 21.4 | 29.6 | 40.5 | 64.0 | 31.6 | 42.6 | 28.1 | 36.0 |
| | std dev | | 0.39 | 1.03 | 2.07 | 1.19 | 1.24 | 3.03 | 0.65 | 3.95 | 3.19 | 5.26 |

| parent material | solution | # | IRON DATA µmol/L run 1 | run 2 | run 3 | run 4 | run 5 | MAGNESIUM DATA µmol/L run 1 | run 2 | run 3 | run 4 | run 5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Marlow | FF-MED | 1 | 4.91 | 9.90 | 18.3 | 20.1 | 24.4 | 59.2 | 36.8 | 44.4 | 31.3 | 46.9 |
| Marlow | FF-MED | 2 | 5.01 | 14.5 | 18.3 | 16.5 | 20.8 | 55.1 | 32.9 | 41.1 | 34.8 | 36.8 |
| Marlow | FF-MED | 3 | 4.44 | 11.0 | 18.1 | 19.3 | 22.7 | 53.9 | 31.8 | 39.8 | 36.5 | 38.5 |
| | mean | | 4.79 | 11.8 | 18.2 | 18.6 | 22.6 | 56.1 | 33.8 | 41.8 | 34.2 | 40.7 |
| | std dev | | 0.30 | 2.38 | 0.10 | 1.85 | 1.79 | 2.80 | 2.64 | 2.37 | 2.63 | 5.41 |
| Success | FF-MED | 1 | 7.22 | 11.2 | 16.8 | 24.7 | 26.5 | 64.6 | 35.2 | 42.4 | 25.0 | 35.6 |
| Success | FF-MED | 2 | 7.29 | 10.0 | 18.8 | 20.8 | 23.3 | 60.1 | 30.9 | 38.3 | 31.1 | 32.6 |
| Success | FF-MED | 3 | 7.65 | 11.4 | 20.4 | 24.7 | 27.2 | 65.4 | 33.5 | 38.9 | 27.6 | 34.3 |
| | mean | | 7.38 | 10.9 | 18.7 | 23.4 | 25.7 | 63.3 | 33.2 | 39.9 | 27.9 | 34.2 |
| | std dev | | 0.23 | 0.73 | 1.79 | 2.27 | 2.10 | 2.88 | 2.18 | 2.18 | 3.05 | 1.49 |
| Lombard | FF-MED | 1 | 10.8 | 16.5 | 38.1 | 32.4 | 33.1 | 79.0 | 83.5 | 123 | 58.4 | 85.1 |
| Lombard | FF-MED | 2 | 10.1 | 16.0 | 40.8 | 36.7 | 37.4 | 72.4 | 82.7 | 128 | 52.6 | 79.8 |
| Lombard | FF-MED | 3 | 10.5 | 17.3 | 42.6 | 34.4 | 44.4 | 75.7 | 79.0 | 124 | 55.4 | 84.3 |
| | mean | | 10.5 | 16.6 | 40.5 | 34.5 | 38.3 | 75.7 | 81.7 | 125 | 55.5 | 83.1 |
| | std dev | | 0.31 | 0.69 | 2.25 | 2.06 | 5.69 | 3.29 | 2.41 | 2.41 | 4.07 | 2.88 |
| Hermon | FF-HIGH | 1 | 16.8 | 46.2 | 66.1 | 65.0 | 86.3 | 144 | 65.4 | 102 | 57.2 | 65.8 |
| Hermon | FF-HIGH | 2 | 15.2 | 42.1 | 92.9 | 64.3 | 88.1 | 132 | 62.5 | 79.4 | 58.4 | 70.7 |
| Hermon | FF-HIGH | 3 | 15.9 | 31.0 | 98.1 | 67.0 | 82.7 | 132 | 60.5 | 77.7 | 57.2 | 67.0 |
| | mean | | 16.0 | 39.8 | 85.7 | 65.4 | 85.7 | 136 | 62.8 | 86.2 | 57.3 | 67.9 |
| | std dev | | 0.81 | 7.87 | 17.20 | 1.28 | 2.74 | 6.66 | 2.48 | 13.3 | 0.57 | 2.57 |
| Marlow | FF-HIGH | 1 | 11.5 | 30.4 | 68.0 | 52.8 | 69.8 | 123 | 76.1 | 107 | 93.0 | 86.4 |
| Marlow | FF-HIGH | 2 | 15.5 | 22.9 | 47.6 | 41.0 | 49.8 | 135 | 63.3 | 79.8 | 74.9 | 74.9 |
| Marlow | FF-HIGH | 3 | 16.5 | 26.0 | 43.7 | 50.5 | 59.3 | 141 | 64.2 | 84.3 | 64.6 | 67.0 |
| | mean | | 14.5 | 26.4 | 53.1 | 48.1 | 59.6 | 133 | 67.9 | 90.5 | 77.5 | 76.1 |
| | std dev | | 2.64 | 3.78 | 13.1 | 6.26 | 10.0 | 9.16 | 7.14 | 14.8 | 14.4 | 9.7 |
| Success | FF-HIGH | 1 | 15.9 | 44.6 | 96.5 | 68.2 | 87.0 | 139 | 67.5 | 95.4 | 76.9 | 71.6 |
| Success | FF-HIGH | 2 | 17.1 | 25.6 | 61.6 | 66.4 | 83.8 | 140 | 62.5 | 87.2 | 72.0 | 63.3 |
| Success | FF-HIGH | 3 | 15.9 | 22.7 | 80.0 | 65.2 | 82.5 | 133 | 60.1 | 80.2 | 59.6 | 64.6 |
| | mean | | 16.3 | 31.0 | 79.4 | 66.6 | 84.5 | 138 | 63.3 | 87.6 | 69.5 | 66.5 |
| | std dev | | 0.71 | 11.9 | 17.5 | 1.53 | 2.31 | 3.82 | 3.77 | 7.62 | 8.90 | 4.44 |
| Lombard | FF-HIGH | 1 | 20.6 | 57.3 | 145 | 131 | 122 | 145 | 135 | 169 | 108 | 135 |
| Lombard | FF-HIGH | 2 | 24.0 | 69.8 | 193 | 145 | 131 | 143 | 145 | 180 | 91.7 | 100 |
| Lombard | FF-HIGH | 3 | 19.5 | 37.2 | 84.0 | 86.1 | 102 | 144 | 120 | 169 | 101 | 117 |
| | mean | | 21.4 | 54.8 | 141 | 121 | 118 | 144 | 133 | 173 | 100 | 118 |
| | std dev | | 2.34 | 16.4 | 54.8 | 30.6 | 14.5 | 0.86 | 12.4 | 6.19 | 8.06 | 17.5 |

SILICA AND POTASSIUM OUTFLOW SOLUTION DATA FOR COLUMN STUDY 1.

| | | | SILICA DATA µmol/L | | | | | POTASSIUM DATA µmol/L | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| parent material | solution | # | run 1 | run 2 | run 3 | run 4 | run 5 | run 1 | run 2 | run 3 | run 4 | run 5 |
| Hermon | DW | 1 | 4.94 | 3.17 | 8.30 | 5.32 | 7.14 | 0.26 | 0.69 | 0.28 | 0.13 | 0.18 |
| Hermon | DW | 2 | 5.59 | 4.97 | 9.96 | 7.55 | 6.95 | 0.23 | 0.49 | 0.20 | 0.08 | 0.10 |
| Hermon | DW | 3 | 7.97 | 4.07 | 9.96 | 8.43 | 7.23 | 0.20 | 0.64 | 0.13 | 0.05 | 1.82 |
| | mean | | 6.16 | 4.07 | 9.40 | 7.10 | 7.10 | 0.23 | 0.61 | 0.20 | 0.09 | 0.70 |
| | std dev | | 1.60 | 0.90 | 0.96 | 1.60 | 0.14 | 0.03 | 0.11 | 0.08 | 0.04 | 0.97 |
| Marlow | DW | 1 | 9.70 | 7.84 | 11.8 | 9.77 | 8.05 | 0.15 | 0.64 | 0.10 | 0.13 | 0.51 |
| Marlow | DW | 2 | 14.3 | 8.02 | 11.6 | 9.99 | 8.05 | 0.23 | 0.61 | 0.15 | 0.92 | 0.15 |
| Marlow | DW | 3 | 12.3 | 7.12 | 11.6 | 9.54 | 7.78 | 0.23 | 0.23 | 1.23 | 0.15 | 0.18 |
| | mean | | 12.1 | 7.66 | 11.7 | 9.77 | 7.96 | 0.20 | 0.49 | 0.49 | 0.40 | 0.28 |
| | std dev | | 2.28 | 0.47 | 0.11 | 0.22 | 0.16 | 0.04 | 0.23 | 0.64 | 0.45 | 0.20 |
| Success | DW | 1 | 6.24 | 6.22 | 11.6 | 10.7 | 8.60 | 0.33 | 0.69 | 0.31 | 0.01 | 0.13 |
| Success | DW | 2 | 7.54 | 5.33 | 12.0 | 12.2 | 8.60 | 0.77 | 0.54 | 0.20 | 0.00 | 0.08 |
| Success | DW | 3 | 9.27 | 5.87 | 11.2 | 8.66 | 7.96 | 0.20 | 0.51 | 0.08 | 0.01 | 0.10 |
| | mean | | 7.68 | 5.81 | 11.6 | 10.5 | 8.39 | 0.43 | 0.58 | 0.20 | 0.01 | 0.10 |
| | std dev | | 1.52 | 0.45 | 0.37 | 1.78 | 0.37 | 0.29 | 0.10 | 0.12 | <0.01 | 0.04 |
| Lombard | DW | 1 | 11.9 | 9.45 | 19.9 | 16.0 | 11.3 | 1.59 | 0.59 | 0.64 | 0.28 | 0.20 |
| Lombard | DW | 2 | 17.7 | 13.2 | 24.2 | 18.4 | 15.8 | 0.51 | 0.54 | 0.74 | 0.23 | 0.13 |
| Lombard | DW | 3 | 30.1 | 19.1 | 27.7 | 21.5 | 16.2 | 0.26 | 0.66 | 0.49 | 0.28 | 0.15 |
| | mean | | 19.9 | 13.9 | 23.9 | 18.6 | 14.4 | 0.78 | 0.60 | 0.62 | 0.26 | 0.16 |
| | std dev | | 9.29 | 4.89 | 3.88 | 2.78 | 2.76 | 0.71 | 0.06 | 0.13 | 0.03 | 0.04 |
| Hermon | HNO3 | 1 | 23.3 | 22.0 | 38.6 | 30.9 | 25.4 | 0.31 | 0.79 | 0.82 | 0.28 | 0.54 |
| Hermon | HNO3 | 2 | 27.0 | 26.9 | 41.9 | 44.6 | 39.0 | 0.23 | 0.72 | 0.43 | 0.36 | 0.66 |
| Hermon | HNO3 | 3 | 19.2 | 21.8 | 31.7 | 30.2 | 23.3 | 0.23 | 0.97 | 0.33 | 3.15 | 0.49 |
| | mean | | 23.2 | 23.6 | 37.4 | 35.2 | 29.2 | 0.26 | 0.83 | 0.53 | 1.26 | 0.56 |
| | std dev | | 3.90 | 2.85 | 5.17 | 8.15 | 8.51 | 0.04 | 0.13 | 0.26 | 1.63 | 0.09 |
| Marlow | HNO3 | 1 | 51.9 | 51.6 | 72.7 | 64.2 | 53.9 | 0.64 | 1.28 | 1.18 | 1.38 | 1.82 |
| Marlow | HNO3 | 2 | 55.0 | 52.5 | 71.0 | 62.4 | 58.0 | 0.77 | 0.59 | 1.05 | 1.07 | 1.46 |
| Marlow | HNO3 | 3 | 66.7 | 59.7 | 78.2 | 65.7 | 64.9 | 0.64 | 0.92 | 1.25 | 1.15 | 1.71 |
| | mean | | 57.9 | 54.6 | 74.0 | 64.1 | 58.9 | 0.68 | 0.93 | 1.16 | 1.20 | 1.66 |
| | std dev | | 7.78 | 4.43 | 3.77 | 1.67 | 5.57 | 0.07 | 0.35 | 0.10 | 0.16 | 0.18 |

| parent material | solution | # | SILICA DATA µmol/L run 1 | run 2 | run 3 | run 4 | run 5 | POTASSIUM DATA µmol/L run 1 | run 2 | run 3 | run 4 | run 5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Success | HNO3 | 1 | 58.7 | 54.9 | 79.1 | 73.5 | 69.8 | 0.79 | 0.97 | 15.3 | 1.48 | 2.07 |
| Success | HNO3 | 2 | 52.4 | 54.7 | 77.3 | 76.6 | 73.2 | 0.95 | 1.18 | 1.48 | 1.46 | 1.79 |
| Success | HNO3 | 3 | 59.3 | 54.7 | 78.4 | 71.0 | 72.8 | 2.02 | 0.79 | 1.28 | 1.25 | 1.43 |
| | mean | | 56.8 | 54.7 | 78.3 | 73.7 | 71.9 | 1.25 | 0.98 | 6.04 | 1.40 | 1.76 |
| | std dev | | 3.83 | 0.10 | 0.93 | 2.78 | 1.86 | 0.67 | 0.19 | 8.06 | 0.13 | 0.32 |
| Lombard | HNO3 | 1 | 78.2 | 77.5 | 109 | 89.5 | 84.8 | 79.0 | 70.3 | 70.3 | 71.4 | 57.5 |
| Lombard | HNO3 | 2 | 48.3 | 59.7 | 90.0 | 78.2 | 71.0 | 48.1 | 52.9 | 55.0 | 50.6 | 48.3 |
| Lombard | HNO3 | 3 | 61.3 | 63.1 | 93.9 | 80.2 | 61.6 | 60.4 | 53.4 | 60.9 | 61.4 | 39.6 |
| | mean | | 62.6 | 66.8 | 97.5 | 82.6 | 72.5 | 62.5 | 58.9 | 62.1 | 61.1 | 48.5 |
| | std dev | | 15.0 | 9.43 | 9.83 | 6.04 | 11.7 | 15.6 | 9.90 | 7.74 | 10.4 | 8.95 |
| Hermon | FF-LOW | 1 | 19.0 | 15.9 | 29.0 | 25.1 | 29.2 | 11.2 | 4.07 | 5.86 | 3.78 | 3.89 |
| Hermon | FF-LOW | 2 | 22.0 | 18.8 | 45.0 | 38.9 | 35.9 | 7.83 | 4.42 | 5.27 | 3.35 | 3.71 |
| Hermon | FF-LOW | 3 | 26.8 | 22.9 | 48.0 | 40.0 | 37.4 | 7.11 | 3.96 | 5.34 | 3.27 | 4.22 |
| | mean | | 22.6 | 19.2 | 40.6 | 34.6 | 34.2 | 8.70 | 4.15 | 5.49 | 3.47 | 3.94 |
| | std dev | | 3.93 | 3.52 | 10.2 | 8.29 | 4.35 | 2.16 | 0.24 | 0.32 | 0.28 | 0.26 |
| Marlow | FF-LOW | 1 | 25.1 | 20.6 | 40.0 | 30.0 | 34.6 | 7.80 | 4.32 | 4.50 | 2.97 | 5.37 |
| Marlow | FF-LOW | 2 | 29.0 | 22.9 | 43.7 | 34.6 | 38.4 | 6.19 | 4.83 | 4.96 | 3.04 | 4.22 |
| Marlow | FF-LOW | 3 | 29.0 | 21.7 | 40.6 | 36.4 | 35.9 | 7.01 | 3.73 | 5.14 | 3.25 | 4.04 |
| | mean | | 27.7 | 21.7 | 41.4 | 33.7 | 36.3 | 7.00 | 4.30 | 4.87 | 3.09 | 4.54 |
| | std dev | | 2.25 | 1.17 | 1.99 | 3.33 | 1.95 | 0.81 | 0.55 | 0.33 | 0.15 | 0.72 |
| Success | FF-LOW | 1 | 21.8 | 19.0 | 38.9 | 33.3 | 33.3 | 8.34 | 4.65 | 6.83 | 3.78 | 4.65 |
| Success | FF-LOW | 2 | 22.9 | 19.5 | 44.5 | 37.3 | 35.5 | 7.93 | 4.50 | 5.34 | 3.40 | 4.91 |
| Success | FF-LOW | 3 | 24.6 | 21.8 | 43.9 | 31.5 | 34.9 | 7.39 | 4.27 | 5.29 | 3.20 | 4.73 |
| | mean | | 23.1 | 20.1 | 42.4 | 34.0 | 34.6 | 7.89 | 4.48 | 5.82 | 3.46 | 4.77 |
| | std dev | | 1.42 | 1.53 | 3.05 | 2.96 | 1.15 | 0.47 | 0.19 | 0.87 | 0.30 | 0.13 |
| Lombard | FF-LOW | 1 | 27.7 | 23.1 | 50.0 | 37.3 | 40.3 | 10.5 | 11.4 | 24.9 | 16.4 | 21.1 |
| Lombard | FF-LOW | 2 | 36.3 | 34.6 | 62.2 | 46.0 | 46.7 | 9.10 | 13.0 | 23.2 | 14.4 | 18.6 |
| Lombard | FF-LOW | 3 | 32.2 | 29.0 | 56.8 | 47.3 | 48.3 | 8.80 | 10.9 | 17.9 | 12.5 | 15.6 |
| | mean | | 32.1 | 28.9 | 56.3 | 43.5 | 45.1 | 9.48 | 11.8 | 22.0 | 14.4 | 18.4 |
| | std dev | | 4.33 | 5.74 | 6.10 | 5.43 | 4.26 | 0.93 | 1.13 | 3.63 | 1.92 | 2.78 |
| Hermon | FF-MED | 1 | 80.5 | 68.9 | 150 | 123 | 143 | 41.9 | 19.5 | 24.3 | 19.3 | 25.8 |
| Hermon | FF-MED | 2 | 83.4 | 74.4 | 170 | 129 | 147 | 39.1 | 20.1 | 26.1 | 15.4 | 22.1 |
| Hermon | FF-MED | 3 | 83.8 | 84.8 | 189 | 151 | 147 | 38.4 | 19.3 | 29.2 | 17.7 | 19.3 |
| | mean | | 82.6 | 76.0 | 170 | 135 | 146 | 39.8 | 19.6 | 26.5 | 17.5 | 22.4 |
| | std dev | | 1.76 | 8.11 | 19.6 | 14.9 | 1.98 | 1.89 | 0.41 | 2.46 | 1.98 | 3.27 |

| parent material | solution | # | SILICA DATA µmol/L run 1 | run 2 | run 3 | run 4 | run 5 | POTASSIUM DATA µmol/L run 1 | run 2 | run 3 | run 4 | run 5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Marlow | FF-MED | 1 | 91.2 | 94.3 | 178 | 131 | 155 | 36.8 | 22.9 | 27.6 | 19.5 | 29.2 |
| Marlow | FF-MED | 2 | 92.7 | 97.2 | 175 | 159 | 170 | 34.3 | 20.5 | 25.6 | 21.7 | 22.9 |
| Marlow | FF-MED | 3 | 95.5 | 94.7 | 178 | 159 | 173 | 33.5 | 19.8 | 24.8 | 22.7 | 23.9 |
| | mean | | 93.1 | 95.4 | 177 | 150 | 166 | 34.9 | 21.0 | 26.0 | 21.3 | 25.3 |
| | std dev | | 2.20 | 1.56 | 1.87 | 15.8 | 9.79 | 1.74 | 1.64 | 1.48 | 1.63 | 3.36 |
| Success | FF-MED | 1 | 89.6 | 81.1 | 144 | 111 | 129 | 40.2 | 21.9 | 26.3 | 15.5 | 22.1 |
| Success | FF-MED | 2 | 86.8 | 78.2 | 144 | 123 | 136 | 37.3 | 19.2 | 23.8 | 19.3 | 20.3 |
| Success | FF-MED | 3 | 88.1 | 79.3 | 135 | 120 | 131 | 40.7 | 20.8 | 24.2 | 17.2 | 21.3 |
| | mean | | 88.2 | 79.5 | 141 | 118 | 132 | 39.4 | 20.6 | 24.8 | 17.3 | 21.2 |
| | std dev | | 1.41 | 1.45 | 5.12 | 5.80 | 3.33 | 1.79 | 1.35 | 1.36 | 1.90 | 0.92 |
| Lombard | FF-MED | 1 | 95.3 | 75.9 | 166 | 137 | 140 | 49.1 | 51.9 | 76.7 | 36.3 | 52.9 |
| Lombard | FF-MED | 2 | 99.4 | 88.6 | 186 | 144 | 158 | 45.0 | 51.4 | 79.5 | 32.7 | 49.6 |
| Lombard | FF-MED | 3 | 95.9 | 86.6 | 179 | 147 | 148 | 47.1 | 49.1 | 77.2 | 34.3 | 52.4 |
| | mean | | 96.9 | 83.7 | 177 | 143 | 149 | 47.1 | 50.8 | 77.8 | 34.5 | 51.7 |
| | std dev | | 2.21 | 6.86 | 10.2 | 5.12 | 9.28 | 2.05 | 1.50 | 1.50 | 2.53 | 1.79 |
| Hermon | FF-HIGH | 1 | 164 | 158 | 331 | 225 | 255 | 89.3 | 40.7 | 63.2 | 35.2 | 40.9 |
| Hermon | FF-HIGH | 2 | 159 | 151 | 305 | 235 | 271 | 82.3 | 38.9 | 49.4 | 35.8 | 44.0 |
| Hermon | FF-HIGH | 3 | 158 | 145 | 302 | 210 | 260 | 81.8 | 37.6 | 48.3 | 35.5 | 41.7 |
| | mean | | 160 | 151 | 313 | 223 | 262 | 84.5 | 39.0 | 53.6 | 35.5 | 42.2 |
| | std dev | | 3.45 | 6.65 | 15.7 | 12.5 | 8.13 | 4.14 | 1.54 | 8.3 | 0.02 | 1.60 |
| Marlow | FF-HIGH | 1 | 184 | 208 | 396 | 358 | 363 | 76.7 | 47.3 | 66.7 | 57.8 | 53.7 |
| Marlow | FF-HIGH | 2 | 170 | 154 | 316 | 291 | 340 | 83.9 | 39.4 | 49.6 | 46.5 | 46.5 |
| Marlow | FF-HIGH | 3 | 171 | 141 | 280 | 241 | 269 | 88.0 | 39.9 | 52.4 | 40.2 | 41.7 |
| | mean | | 175 | 167 | 330 | 296 | 324 | 82.9 | 42.2 | 56.3 | 48.2 | 47.3 |
| | std dev | | 7.89 | 35.4 | 59.2 | 58.8 | 49.2 | 5.70 | 4.44 | 9.19 | 8.93 | 6.05 |
| Success | FF-HIGH | 1 | 161 | 172 | 329 | 259 | 281 | 86.7 | 41.9 | 59.3 | 47.8 | 44.5 |
| Success | FF-HIGH | 2 | 165 | 154 | 324 | 262 | 287 | 87.2 | 38.9 | 54.2 | 44.8 | 39.4 |
| Success | FF-HIGH | 3 | 172 | 153 | 284 | 228 | 275 | 82.9 | 37.3 | 49.9 | 37.1 | 40.2 |
| | mean | | 166 | 160 | 312 | 250 | 281 | 85.6 | 39.4 | 54.5 | 43.2 | 41.3 |
| | std dev | | 5.57 | 10.6 | 24.9 | 18.6 | 5.96 | 2.38 | 2.34 | 4.74 | 5.53 | 2.76 |
| Lombard | FF-HIGH | 1 | 174 | 189 | 315 | 250 | 309 | 90.0 | 83.6 | 105 | 67.0 | 84.1 |
| Lombard | FF-HIGH | 2 | 184 | 195 | 327 | 256 | 279 | 89.0 | 90.0 | 112 | 57.0 | 62.4 |
| Lombard | FF-HIGH | 3 | 181 | 169 | 290 | 246 | 285 | 89.3 | 74.7 | 105 | 62.9 | 72.6 |
| | mean | | 180 | 184 | 311 | 251 | 291 | 89.4 | 82.8 | 107 | 62.3 | 73.1 |
| | std dev | | 5.16 | 13.3 | 18.9 | 4.7 | 15.9 | 0.53 | 7.71 | 3.85 | 5.01 | 10.9 |

SOIL CHEMISTRY DATA FOR SOILS FOLLOWING 1-YEAR OF LEACHING

| parent material | solution | LOI | Alo | Feo | Sio | Alp | Fep | Sip | Cp | CHN-C | CHN-H | CHN-N | pH water | pH KCl |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | % | | | | | | | | | | | | |
| Hermon | DW | 0.43 | 0.165 | 0.248 | 0.090 | 0.056 | 0.040 | 0.025 | 0.050 | 0.06 | 0.09 | 0.01 | 6.2 | 5.7 |
| Hermon | DW | 0.56 | 0.164 | 0.217 | 0.087 | 0.056 | 0.040 | 0.023 | 0.047 | | | | 6.2 | 5.9 |
| Hermon | DW | 0.60 | | | | | | | | | | | | |
| | mean | 0.53 | 0.164 | 0.232 | 0.088 | 0.056 | 0.040 | 0.024 | 0.049 | | | | 6.2 | 5.8 |
| | std dev | 0.09 | 0.001 | 0.022 | 0.002 | <0.001 | <0.001 | 0.001 | 0.002 | | | | <0.1 | 0.1 |
| Marlow | DW | 0.48 | 0.259 | 0.168 | 0.126 | 0.114 | 0.039 | 0.022 | 0.067 | 0.10 | 0.08 | 0.01 | 6.2 | 5.5 |
| Marlow | DW | 0.50 | 0.255 | 0.173 | 0.118 | 0.106 | 0.035 | 0.020 | 0.079 | | | | 6.2 | 5.6 |
| Marlow | DW | 0.54 | | | | | | | | | | | | |
| | mean | 0.51 | 0.257 | 0.170 | 0.122 | 0.110 | 0.037 | 0.021 | 0.073 | | | | 6.2 | 5.6 |
| | std dev | 0.03 | 0.003 | 0.003 | 0.005 | 0.006 | 0.003 | 0.002 | 0.009 | | | | 0.0 | 0.1 |
| Success | DW | 0.38 | 0.141 | 0.115 | 0.063 | 0.075 | 0.028 | 0.021 | 0.045 | 0.07 | 0.04 | 0.01 | 6.2 | 6.0 |
| Success | DW | 0.40 | 0.142 | 0.117 | 0.063 | 0.074 | 0.029 | 0.022 | 0.018 | | | | 6.2 | 6.0 |
| Success | DW | 0.39 | | | | | | | | | | | | |
| | mean | 0.39 | 0.141 | 0.116 | 0.063 | 0.075 | 0.028 | 0.022 | 0.032 | | | | 6.2 | 6.0 |
| | std dev | 0.01 | <0.001 | 0.002 | <0.001 | 0.001 | <0.001 | 0.001 | 0.019 | | | | <0.1 | <0.1 |
| Lombard | DW | 0.66 | 0.132 | 0.405 | 0.129 | 0.035 | 0.045 | 0.022 | 0.003 | 0.20 | 0.24 | 0.02 | 6.3 | 5.5 |
| Lombard | DW | 0.58 | 0.125 | 0.386 | 0.125 | 0.036 | 0.052 | 0.021 | 0.022 | | | | 6.2 | 5.5 |
| Lombard | DW | 0.74 | | | | | | | | | | | | |
| | mean | 0.66 | 0.128 | 0.395 | 0.127 | 0.035 | 0.049 | 0.022 | 0.013 | | | | 6.2 | 5.5 |
| | std dev | 0.08 | 0.005 | 0.014 | 0.003 | <0.001 | 0.005 | <0.001 | 0.014 | | | | <0.1 | <0.1 |
| Hermon | $HNO_3$ | 0.52 | 0.122 | 0.290 | 0.073 | 0.047 | 0.030 | 0.019 | 0.046 | 0.06 | 0.07 | 0.00 | 5.9 | 5.0 |
| Hermon | $HNO_3$ | 0.49 | 0.118 | 0.275 | 0.071 | 0.046 | 0.030 | 0.021 | 0.047 | | | | 5.8 | 4.9 |
| Hermon | $HNO_3$ | 0.50 | | | | | | | | | | | | |
| | mean | 0.50 | 0.120 | 0.283 | 0.072 | 0.046 | 0.030 | 0.020 | 0.047 | | | | 5.8 | 5.0 |
| | std dev | 0.02 | 0.003 | 0.011 | 0.001 | <0.001 | <0.001 | 0.002 | 0.001 | | | | <0.1 | 0.1 |
| Marlow | $HNO_3$ | 0.37 | 0.170 | 0.123 | 0.069 | 0.091 | 0.034 | 0.021 | 0.068 | 0.10 | 0.11 | 0.02 | 5.5 | 4.7 |
| Marlow | $HNO_3$ | 0.41 | 0.169 | 0.125 | 0.069 | 0.093 | 0.035 | 0.021 | 0.059 | | | | 5.5 | 4.8 |
| Marlow | $HNO_3$ | 0.45 | | | | | | | | | | | | |
| | mean | 0.41 | 0.170 | 0.124 | 0.069 | 0.092 | 0.035 | 0.021 | 0.063 | | | | 5.5 | 4.7 |
| | std dev | 0.04 | 0.001 | 0.001 | 0.001 | 0.002 | <0.001 | <0.001 | 0.006 | | | | <0.1 | <0.1 |
| Success | $HNO_3$ | 0.30 | 0.116 | 0.116 | 0.053 | 0.057 | 0.031 | 0.023 | 0.063 | 0.06 | 0.06 | 0.01 | 5.7 | 4.8 |
| Success | $HNO_3$ | 0.35 | 0.115 | 0.133 | 0.055 | 0.057 | 0.031 | 0.023 | 0.048 | | | | 5.8 | 4.9 |
| Success | $HNO_3$ | 0.36 | | | | | | | | | | | | |
| | mean | 0.34 | 0.115 | 0.125 | 0.054 | 0.057 | 0.031 | 0.023 | 0.055 | | | | 5.7 | 4.8 |
| | std dev | 0.03 | <0.001 | 0.011 | 0.001 | <0.001 | <0.001 | <0.001 | 0.010 | | | | 0.1 | <0.1 |

| parent material | solution | LOI | Alo | Feo | Sio | Alp | Fep | Sip | Cp | CHN-C | CHN-H | CHN-N | pH water | pH KCl |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | % | | | | | | | |
| Lombard | $HNO_3$ | 0.49 | 0.101 | 0.358 | 0.085 | 0.034 | 0.049 | 0.027 | 0.000 | 0.17 | 0.24 | 0.02 | 5.7 | 4.4 |
| Lombard | $HNO_3$ | 0.50 | 0.113 | 0.396 | 0.090 | 0.032 | 0.046 | 0.020 | 0.000 | | | | 5.7 | 4.5 |
| Lombard | $HNO_3$ | 0.67 | | | | | | | | | | | | |
| | mean | 0.55 | 0.107 | 0.377 | 0.087 | 0.033 | 0.047 | 0.023 | 0.000 | | | | 5.7 | 4.5 |
| | std dev | 0.10 | 0.009 | 0.027 | 0.004 | 0.001 | 0.002 | 0.005 | <0.001 | | | | <0.1 | 0.1 |
| Hermon | FF-low | 0.57 | 0.126 | 0.168 | 0.057 | 0.570 | 0.035 | 0.025 | 0.036 | 0.09 | 0.08 | 0.02 | 6.1 | 5.4 |
| Hermon | FF-low | 0.66 | 0.127 | 0.174 | 0.062 | 0.540 | 0.033 | 0.022 | 0.059 | | | | 6.1 | 5.5 |
| Hermon | FF-low | 0.51 | | | | | | | | | | | | |
| | mean | 0.58 | 0.126 | 0.171 | 0.059 | 0.550 | 0.034 | 0.024 | 0.047 | | | | 6.1 | 5.5 |
| | std dev | 0.08 | 0.001 | 0.004 | 0.003 | 0.002 | 0.001 | 0.002 | 0.016 | | | | <0.1 | 0.1 |
| Marlow | FF-low | 0.64 | 0.204 | 0.138 | 0.087 | 0.101 | 0.033 | 0.019 | 0.071 | 0.17 | 0.11 | 0.01 | 5.9 | 5.0 |
| Marlow | FF-low | 0.69 | 0.209 | 0.134 | 0.084 | 0.104 | 0.033 | 0.020 | 0.064 | | | | 5.8 | 4.9 |
| Marlow | FF-low | 0.66 | | | | | | | 0.073 | | | | | |
| | mean | 0.66 | 0.207 | 0.136 | 0.085 | 0.102 | 0.033 | 0.020 | 0.069 | | | | 5.8 | 4.9 |
| | std dev | 0.02 | 0.004 | 0.003 | 0.002 | 0.003 | <0.001 | 0.001 | 0.050 | | | | 0.1 | <0.1 |
| Success | FF-low | 0.46 | 0.133 | 0.115 | 0.058 | 0.064 | 0.026 | 0.020 | 0.044 | 0.10 | 0.05 | 0.01 | 5.9 | 5.3 |
| Success | FF-low | 0.46 | 0.125 | 0.123 | 0.056 | 0.064 | 0.025 | 0.017 | 0.069 | 0.09 | 0.05 | 0.01 | 6.0 | 5.4 |
| Success | FF-low | 0.51 | | | | | | | | 0.09 | 0.06 | 0.01 | | |
| | mean | 0.48 | 0.129 | 0.119 | 0.057 | 0.064 | 0.025 | 0.018 | 0.056 | | | | 6.0 | 5.3 |
| | std dev | 0.03 | 0.006 | 0.005 | 0.002 | <0.001 | 0.001 | 0.002 | 0.018 | | | | <0.1 | 0.1 |
| Lombard | FF-low | 0.84 | 0.097 | 0.435 | 0.086 | 0.032 | 0.050 | 0.017 | 0.063 | 0.23 | 0.25 | 0.02 | 5.8 | 4.9 |
| Lombard | FF-low | 0.84 | 0.094 | 0.416 | 0.084 | 0.031 | 0.048 | 0.022 | 0.068 | | | | 5.8 | 5.0 |
| Lombard | FF-low | 0.72 | | | | | | | | | | | | |
| | mean | 0.80 | 0.096 | 0.426 | 0.085 | 0.032 | 0.049 | 0.019 | 0.066 | | | | 5.8 | 4.9 |
| | std dev | 0.07 | 0.002 | 0.013 | 0.002 | <0.001 | 0.001 | 0.004 | 0.004 | | | | <0.1 | 0.1 |
| Hermon | FF-medium | 0.85 | 0.158 | 0.221 | 0.083 | 0.073 | 0.054 | 0.032 | 0.140 | 0.22 | 0.11 | 0.01 | 5.9 | 5.2 |
| Hermon | FF-medium | 0.64 | 0.161 | 0.226 | 0.086 | 0.073 | 0.053 | 0.030 | 0.157 | | | | 6.0 | 5.1 |
| Hermon | FF-medium | 0.84 | | | | | | | | | | | | |
| | mean | 0.78 | 0.160 | 0.223 | 0.084 | 0.073 | 0.053 | 0.031 | 0.148 | | | | 5.9 | 5.2 |
| | std dev | 0.11 | 0.002 | 0.004 | 0.002 | <0.001 | 0.001 | 0.001 | 0.012 | | | | <0.1 | 0.1 |
| Marlow | FF-medium | 0.99 | 0.193 | 0.107 | 0.065 | 0.111 | 0.043 | 0.025 | 0.222 | 0.31 | 0.11 | 0.03 | 5.3 | 4.5 |
| Marlow | FF-medium | 1.10 | 0.196 | 0.110 | 0.072 | 0.106 | 0.049 | 0.021 | 0.178 | | | | 5.3 | 4.6 |
| Marlow | FF-medium | 1.00 | | | | | | | | | | | | |
| | mean | 1.03 | 0.194 | 0.108 | 0.069 | 0.108 | 0.046 | 0.023 | 0.200 | | | | 5.3 | 4.6 |
| | std dev | 0.06 | 0.002 | 0.002 | 0.005 | 0.004 | 0.004 | 0.003 | 0.031 | | | | <0.1 | <0.1 |

| parent material | solution | LOI | Alo | Feo | Sio | Alp | Fep | Sip | Cp | CHN-C | CHN-H | CHN-N | pH water | pH KCl |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | % | | | | | | | | | | | | |
| Success | FF-medium | 0.64 | 0.128 | 0.108 | 0.063 | 0.077 | 0.039 | 0.027 | 0.129 | 0.22 | 0.10 | 0.02 | 5.6 | 5.0 |
| Success | FF-medium | 0.61 | 0.131 | 0.121 | 0.062 | 0.072 | 0.037 | 0.024 | 0.139 | | | | 5.7 | 5.0 |
| Success | FF-medium | 0.52 | | | | | | | | | | | | |
| | mean | 0.59 | 0.130 | 0.114 | 0.063 | 0.075 | 0.038 | 0.026 | 0.134 | | | | 5.6 | 5.0 |
| | std dev | 0.06 | 0.002 | 0.009 | 0.001 | 0.003 | 0.001 | 0.002 | 0.007 | | | | <0.1 | <0.1 |
| Lombard | FF-medium | 0.69 | 0.082 | 0.356 | 0.066 | 0.031 | 0.056 | 0.018 | 0.143 | 0.29 | 0.22 | 0.03 | 5.4 | 4.6 |
| Lombard | FF-medium | 0.88 | 0.082 | 0.342 | 0.065 | 0.032 | 0.059 | 0.023 | 0.144 | | | | 5.4 | 4.6 |
| Lombard | FF-medium | 0.85 | | | | | | | | | | | | |
| | mean | 0.81 | 0.082 | 0.349 | 0.065 | 0.031 | 0.057 | 0.021 | 0.143 | | | | 5.4 | 4.6 |
| | std dev | 0.11 | <0.001 | 0.010 | 0.001 | 0.001 | 0.002 | 0.003 | 0.001 | | | | <0.1 | <0.1 |
| Hermon | FF-high | 0.75 | 0.097 | 0.137 | 0.049 | 0.055 | 0.049 | 0.031 | 0.116 | 0.17 | 0.09 | 0.01 | 6.0 | 5.1 |
| Hermon | FF-high | 0.76 | 0.124 | 0.206 | 0.069 | 0.054 | 0.048 | 0.032 | 0.122 | 0.16 | 0.09 | 0.00 | 5.9 | 5.0 |
| Hermon | FF-high | 0.74 | | | | | | | | 0.17 | 0.09 | 0.01 | | |
| | mean | 0.75 | 0.110 | 0.171 | 0.059 | 0.055 | 0.049 | 0.032 | 0.119 | | | | 5.9 | 5.0 |
| | std dev | 0.01 | 0.019 | 0.049 | 0.014 | <0.001 | <0.001 | 0.001 | 0.004 | | | | 0.1 | 0.1 |
| Marlow | FF-high | 1.12 | 0.242 | 0.153 | 0.099 | 0.135 | 0.063 | 0.027 | 0.379 | 0.53 | 0.14 | 0.03 | 5.0 | 4.4 |
| Marlow | FF-high | 1.40 | 0.247 | 0.151 | 0.100 | 0.138 | 0.067 | 0.028 | 0.341 | | | | 5.0 | 4.4 |
| Marlow | FF-high | 1.34 | | | | | | | | | | | | |
| | mean | 1.29 | 0.244 | 0.152 | 0.100 | 0.136 | 0.065 | 0.028 | 0.360 | | | | 5.0 | 4.4 |
| | std dev | 0.15 | 0.003 | 0.001 | 0.001 | 0.002 | 0.003 | 0.001 | 0.027 | | | | <0.1 | <0.1 |
| Success | FF-high | 0.58 | 0.127 | 0.117 | 0.063 | 0.070 | 0.044 | 0.027 | 0.176 | 0.23 | 0.07 | 0.02 | 5.9 | 5.1 |
| Success | FF-high | 0.62 | 0.124 | 0.106 | 0.059 | 0.071 | 0.045 | 0.026 | 0.161 | | | | 5.9 | 5.1 |
| Success | FF-high | 0.54 | | | | | | | 0.247 | | | | | |
| | mean | 0.58 | 0.126 | 0.111 | 0.061 | 0.070 | 0.044 | 0.027 | 0.195 | | | | 5.9 | 5.1 |
| | std dev | 0.04 | 0.003 | 0.008 | 0.003 | <0.001 | <0.001 | 0.001 | 0.046 | | | | <0.1 | <0.1 |
| Lombard | FF-high | 0.87 | 0.096 | 0.373 | 0.077 | 0.039 | 0.089 | 0.025 | 0.138 | 0.35 | 0.22 | 0.08 | 5.1 | 4.4 |
| Lombard | FF-high | 0.85 | 0.093 | 0.366 | 0.077 | 0.034 | 0.077 | 0.020 | 0.153 | | | | 5.3 | 4.4 |
| Lombard | FF-high | 1.02 | | | | | | | | | | | | |
| | mean | 0.91 | 0.094 | 0.370 | 0.077 | 0.037 | 0.083 | 0.023 | 0.146 | | | | 5.2 | 4.4 |
| | std dev | 0.09 | 0.020 | 0.005 | 0.001 | 0.004 | 0.009 | 0.003 | 0.011 | | | | 0.2 | <0.1 |
| Hermon | P.M. | 0.59 | 0.115 | 0.137 | 0.048 | 0.052 | 0.035 | 0.022 | 0.029 | 0.06 | 0.11 | 0.01 | 5.7 | 5.4 |
| Hermon | P.M. | 0.54 | 0.115 | 0.014 | 0.050 | 0.049 | 0.027 | 0.019 | 0.030 | | | | 5.9 | 5.4 |
| Hermon | P.M. | 0.53 | | | | | | | | | | | | |
| | mean | 0.55 | 0.115 | 0.138 | 0.049 | 0.050 | 0.031 | 0.020 | 0.029 | | | | 5.8 | 5.4 |
| | std dev | 0.03 | <0.001 | 0.001 | 0.001 | 0.003 | 0.006 | 0.002 | 0.001 | | | | 0.1 | <0.1 |

| parent material | solution | LOI | Alo | Feo | Sio | Alp | Fep | Sip | Cp | CHN-C | CHN-H | CHN-N | pH water | pH KCl |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | % | | | | | | | | | | | | |
| Marlow | P.M. | 0.58 | 0.174 | 0.081 | 0.065 | 0.076 | 0.028 | 0.016 | 0.056 | 0.10 | 0.09 | 0.00 | 5.9 | 5.2 |
| Marlow | P.M. | 0.51 | 0.167 | 0.077 | 0.058 | 0.081 | 0.023 | 0.022 | 0.060 | | | | 5.9 | 5.1 |
| Marlow | P.M. | 0.54 | | | | | | | | | | | | |
| | mean | 0.54 | 0.171 | 0.079 | 0.061 | 0.078 | 0.026 | 0.019 | 0.058 | | | | 5.9 | 5.1 |
| | std dev | 0.04 | 0.005 | 0.003 | 0.005 | 0.003 | 0.003 | 0.004 | 0.003 | | | | <0.1 | 0.1 |
| Success | P.M. | 0.42 | 0.128 | 0.078 | 0.074 | 0.060 | 0.020 | 0.015 | 0.048 | 0.05 | 0.05 | 0.01 | 6.0 | 5.6 |
| Success | P.M. | 0.52 | 0.121 | 0.075 | 0.059 | 0.059 | 0.020 | 0.015 | 0.050 | | | | 6.1 | 5.7 |
| Success | P.M. | 0.59 | | | | | | | | | | | | |
| | mean | 0.51 | 0.125 | 0.076 | 0.066 | 0.060 | 0.020 | 0.015 | 0.049 | | | | 6.0 | 5.6 |
| | std dev | 0.08 | 0.005 | 0.002 | 0.011 | 0.001 | <0.001 | 0.001 | 0.001 | | | | <0.1 | <0.1 |
| Lombard | P.M. | 0.52 | 0.059 | 0.282 | 0.047 | 0.019 | 0.023 | 0.010 | 0.008 | 0.15 | 0.20 | 0.02 | 6.1 | 5.2 |
| Lombard | P.M. | 0.67 | 0.060 | 0.290 | 0.048 | 0.020 | 0.025 | 0.013 | 0.003 | | | | 6.1 | 5.4 |
| Lombard | P.M. | 0.75 | | | | | | | | | | | | |
| | mean | 0.65 | 0.060 | 0.286 | 0.048 | 0.020 | 0.024 | 0.011 | 0.005 | | | | 6.1 | 5.3 |
| | std dev | 0.12 | 0.001 | 0.005 | <0.001 | 0.001 | 0.001 | 0.002 | 0.004 | | | | <0.1 | 0.1 |

## REASONS FOR COLUMN STUDY 2:

A second column study was established for 69 days using the soil materials collected at the same time and from the same location as the soil materials in the original column study (1 year). DOC solutions were made from forest floor materials collected at the same site as the original column study. Because the first solution sampling period from the original column study was not bulk sampled, but only sampled on the 69$^{th}$ day (after 23 solution additions), there was no true measure of the net loss of materials from soil or solution during the leaching. The second column study was run using the average concentration of DOC for the forest floor treatments calculated from the original column study. Net release of DOC as well as inorganic constituents were measured over 3 time periods (days 12, 21 and 69). The net cumulative release from the second column study for DOC and inorganic constituents was compared to results from the first sampling event from the original column study to determine the magnitude of error associated with the sampling scheme from the early stages of the original column study.

CHEMISTRY OF INPUT SOLUTIONS FOR COLUMN STUDY 2.

| ELEMENT | SOLUTION | RUN 1 | RUN 2 | RUN 3 |
|---|---|---|---|---|
| Al | DW | 0.20 | 0.18 | 0.20 |
| μmol/L | HNO3 | 1.04 | 1.10 | 1.02 |
| | FF-LOW | 6.84 | 6.78 | 4.04 |
| | FF-MEDIUM | 30.7 | 29.8 | 17.9 |
| | FF-HIGH | 70.1 | 70.1 | 35.1 |
| Ca | DW | 0.25 | 0.25 | 0.25 |
| μmol/L | HNO3 | 1.63 | 1.49 | 1.63 |
| | FF-LOW | 12.9 | 13.6 | 13.1 |
| | FF-MEDIUM | 52.2 | 52.1 | 51.9 |
| | FF-HIGH | 115 | 112 | 104 |
| Fe | DW | 0.05 | 0.03 | 0.01 |
| μmol/L | HNO3 | 0.25 | 0.24 | 0.18 |
| | FF-LOW | 2.60 | 2.58 | 1.13 |
| | FF-MEDIUM | 11.9 | 11.9 | 3.92 |
| | FF-HIGH | 25.9 | 26.3 | 7.16 |
| Mg | DW | 0.08 | 0.15 | 0.08 |
| μmol/L | HNO3 | 0.32 | 0.27 | 0.21 |
| | FF-LOW | 3.79 | 3.85 | 4.36 |
| | FF-MEDIUM | 14.3 | 14.8 | 17.1 |
| | FF-HIGH | 34.3 | 32.3 | 35.1 |
| K | DW | 0.42 | 0.38 | 0.41 |
| μmol/L | HNO3 | 0.20 | 0.18 | 0.20 |
| | FF-LOW | 15.5 | 16.0 | 20.8 |
| | FF-MEDIUM | 52.4 | 60.1 | 85.7 |
| | FF-HIGH | 107 | 125 | 172 |
| Si | DW | 1.82 | 0.92 | 1.23 |
| μmol/L | HNO3 | 2.13 | 2.13 | 2.16 |
| | FF-LOW | 3.13 | 5.98 | 6.64 |
| | FF-MEDIUM | 15.9 | 31.2 | 33.4 |
| | FF-HIGH | 33.3 | 60.2 | 64.1 |
| DOC | FF-LOW | 15.1 | 15.2 | 15.4 |
| mg/L | FF-MEDIUM | 74.8 | 75.1 | 76.1 |
| | FF-HIGH | 150 | 150 | 151 |

ALUMINUM AND CALCIUM OUTFLOW SOLUTION DATA FOR COLUMN STUDY 2

| parent material | solution | # | ALUMINUM DATA µmol/L run 1 | run 2 | run 3 | CALCIUM DATA µmol/L run 1 | run 2 | run 3 |
|---|---|---|---|---|---|---|---|---|
| Hermon | DW | 1 | 33.6 | 0.74 | 0.44 | 10.7 | 3.09 | 2.05 |
| Hermon | DW | 2 | 38.9 | 4.71 | 1.22 | 13.2 | 2.45 | 0.85 |
| Hermon | DW | 3 | 36.3 | 1.59 | 0.74 | 10.5 | 2.50 | 1.52 |
| | mean | | 36.3 | 2.35 | 0.80 | 11.5 | 2.68 | 1.47 |
| | std dev | | 2.65 | 2.09 | 0.39 | 1.49 | 0.36 | 0.60 |
| Marlow | DW | 1 | 5.86 | 3.85 | 7.63 | 14.7 | 4.49 | 2.05 |
| Marlow | DW | 2 | 7.86 | 6.60 | 16.6 | 18.7 | 4.32 | 0.92 |
| Marlow | DW | 3 | 8.01 | 4.15 | 34.2 | 18.5 | 3.27 | 2.05 |
| | mean | | 7.24 | 4.87 | 19.5 | 17.3 | 4.03 | 1.67 |
| | std dev | | 1.20 | 1.51 | 13.5 | 2.26 | 0.66 | 0.65 |
| Success | DW | 1 | 5.71 | 24.7 | 2.63 | 9.68 | 8.48 | 0.67 |
| Success | DW | 2 | 8.45 | 7.56 | 7.56 | 15.8 | 3.54 | 0.92 |
| Success | DW | 3 | 8.89 | 11.9 | 6.82 | 17.5 | 3.37 | 0.92 |
| | mean | | 7.68 | 14.7 | 5.67 | 14.3 | 5.13 | 0.84 |
| | std dev | | 1.73 | 8.92 | 2.66 | 4.12 | 2.90 | 0.14 |
| Lombard | DW | 1 | 6.78 | 4.67 | 0.41 | 15.4 | 14.0 | 6.81 |
| Lombard | DW | 2 | 2.30 | 0.78 | 0.41 | 16.2 | 13.5 | 6.74 |
| Lombard | DW | 3 | 1.78 | 1.00 | 2.00 | 14.1 | 12.8 | 10.4 |
| | mean | | 3.62 | 2.15 | 0.94 | 15.3 | 13.4 | 7.98 |
| | std dev | | 2.75 | 2.19 | 0.92 | 1.04 | 0.60 | 2.10 |
| Hermon | HNO3 | 1 | 6.78 | 179 | 158 | 15.4 | 10.5 | 7.06 |
| Hermon | HNO3 | 2 | 2.30 | 178 | 154 | 16.2 | 8.26 | 5.99 |
| Hermon | HNO3 | 3 | 1.78 | 173 | 170 | 14.1 | 9.46 | 6.66 |
| | mean | | 3.62 | 177 | 161 | 15.3 | 9.39 | 6.57 |
| | std dev | | 2.75 | 2.73 | 8.34 | 1.04 | 1.10 | 0.54 |
| Marlow | HNO3 | 1 | 245 | 305 | 248 | 30.4 | 30.4 | 56.9 |
| Marlow | HNO3 | 2 | 252 | 272 | 222 | 34.4 | 30.4 | 54.6 |
| Marlow | HNO3 | 3 | 238 | 259 | 252 | 39.7 | 31.9 | 62.4 |
| mean | | | 245 | 279 | 241 | 34.8 | 30.9 | 58.0 |
| std dev | | | 6.67 | 23.6 | 16.6 | 4.63 | 0.86 | 3.98 |
| Success | HNO3 | 1 | 161 | 225 | 202 | 35.4 | 9.48 | 13.8 |
| Success | HNO3 | 2 | 207 | 291 | 259 | 46.9 | 8.78 | 22.0 |
| Success | HNO3 | 3 | 188 | 269 | 240 | 44.2 | 9.11 | 22.3 |
| | mean | | 185 | 262 | 234 | 42.2 | 9.12 | 19.4 |
| | std dev | | 23.3 | 33.6 | 29.4 | 5.99 | 0.35 | 4.82 |

| parent material | solution | # | ALUMINUM DATA µmol/L run 1 | run 2 | run 3 | CALCIUM DATA µmol/L run 1 | run 2 | run 3 |
|---|---|---|---|---|---|---|---|---|
| Lombard | HNO3 | 1 | 3.41 | 4.15 | 5.78 | 255 | 324 | 349 |
| Lombard | HNO3 | 2 | 3.97 | 3.22 | 4.15 | 225 | 322 | 347 |
| Lombard | HNO3 | 3 | 3.48 | 3.52 | 4.89 | 203 | 292 | 292 |
| | mean | | 3.62 | 3.63 | 4.94 | 227 | 313 | 329 |
| | std dev | | 0.30 | 0.47 | 0.82 | 26.0 | 18.1 | 32.4 |
| Hermon | FF-LOW | 1 | 15.2 | 11.5 | 9.56 | 16.6 | 12.9 | 10.4 |
| Hermon | FF-LOW | 2 | 25.6 | 14.5 | 8.56 | 17.8 | 12.6 | 11.2 |
| Hermon | FF-LOW | 3 | 19.8 | 13.0 | 10.4 | 16.1 | 10.8 | 8.16 |
| | mean | | 20.2 | 13.0 | 9.50 | 16.9 | 12.1 | 9.93 |
| | std dev | | 5.22 | 1.50 | 0.91 | 0.88 | 1.11 | 1.58 |
| Marlow | FF-LOW | 1 | 17.9 | 19.7 | 19.6 | 24.0 | 14.8 | 12.8 |
| Marlow | FF-LOW | 2 | 13.8 | 14.1 | 14.2 | 26.7 | 18.3 | 11.1 |
| Marlow | FF-LOW | 3 | 11.2 | 17.8 | 27.1 | 22.8 | 7.69 | 6.01 |
| | mean | | 14.3 | 17.2 | 20.3 | 24.5 | 13.6 | 9.96 |
| | std dev | | 3.40 | 2.85 | 6.50 | 2.01 | 5.40 | 3.52 |
| Success | FF-LOW | 1 | 46.7 | 22.4 | 14.6 | 18.8 | 14.0 | 10.4 |
| Success | FF-LOW | 2 | 38.9 | 44.5 | 24.0 | 19.9 | 12.3 | 9.61 |
| Success | FF-LOW | 3 | 37.8 | 29.5 | 22.2 | 19.7 | 9.36 | 7.26 |
| | mean | | 41.1 | 32.1 | 20.3 | 19.5 | 11.9 | 9.08 |
| | std dev | | 4.85 | 11.3 | 4.96 | 0.57 | 2.34 | 1.62 |
| Lombard | FF-LOW | 1 | 27.3 | 9.34 | 7.26 | 45.2 | 44.9 | 35.7 |
| Lombard | FF-LOW | 2 | 13.0 | 8.82 | 6.19 | 34.7 | 37.4 | 29.9 |
| Lombard | FF-LOW | 3 | 13.5 | 9.49 | 5.37 | 31.2 | 31.4 | 25.2 |
| | mean | | 17.9 | 9.22 | 6.28 | 37.0 | 37.9 | 30.3 |
| | std dev | | 8.10 | 0.35 | 0.95 | 7.27 | 6.75 | 5.25 |
| Hermon | FF-MEDIUM | 1 | 61.2 | 53.0 | 35.5 | 56.6 | 59.9 | 53.4 |
| Hermon | FF-MEDIUM | 2 | 47.1 | 52.6 | 38.2 | 49.9 | 53.9 | 48.7 |
| Hermon | FF-MEDIUM | 3 | 63.7 | 61.5 | 40.4 | 53.6 | 52.1 | 44.7 |
| | mean | | 57.3 | 55.7 | 38.0 | 53.4 | 55.3 | 48.9 |
| | std dev | | 8.97 | 5.03 | 2.45 | 3.38 | 4.06 | 4.37 |

| parent material | solution | # | ALUMINUM DATA µmol/L run 1 | run 2 | run 3 | CALCIUM DATA µmol/L run 1 | run 2 | run 3 |
|---|---|---|---|---|---|---|---|---|
| Marlow | FF-MEDIUM | 1 | 57.4 | 86.7 | 64.1 | 56.9 | 59.4 | 51.9 |
| Marlow | FF-MEDIUM | 2 | 43.0 | 73.8 | 70.8 | 49.4 | 51.2 | 49.2 |
| Marlow | FF-MEDIUM | 3 | 42.3 | 110 | 81.2 | 40.7 | 43.2 | 47.2 |
| | mean | | 47.6 | 90.3 | 72.0 | 49.0 | 51.2 | 49.4 |
| | std dev | | 8.57 | 18.6 | 8.59 | 8.12 | 8.11 | 2.38 |
| Success | FF-MEDIUM | 1 | 92.3 | 76.0 | 53.0 | 53.1 | 57.4 | 50.4 |
| Success | FF-MEDIUM | 2 | 77.5 | 59.7 | 43.0 | 51.6 | 52.9 | 48.4 |
| Success | FF-MEDIUM | 3 | 105 | 88.2 | 53.4 | 46.2 | 53.1 | 48.2 |
| | mean | | 91.4 | 74.6 | 49.8 | 50.3 | 54.5 | 49.0 |
| | std dev | | 13.5 | 14.3 | 5.89 | 3.68 | 2.52 | 1.23 |
| Lombard | FF-MEDIUM | 1 | 41.5 | 41.9 | 30.2 | 123 | 139 | 139 |
| Lombard | FF-MEDIUM | 2 | 35.8 | 41.1 | 34.1 | 113 | 140 | 132 |
| Lombard | FF-MEDIUM | 3 | 36.7 | 38.9 | 28.4 | 113 | 137 | 126 |
| | mean | | 38.0 | 40.6 | 30.9 | 116 | 139 | 132 |
| | std dev | | 3.08 | 1.54 | 2.88 | 5.55 | 1.50 | 6.86 |
| Hermon | FF-HIGH | 1 | 118 | 120 | 89.7 | 86.6 | 108 | 99.1 |
| Hermon | FF-HIGH | 2 | 102 | 107 | 86.0 | 101 | 109 | 99.3 |
| Hermon | FF-HIGH | 3 | 122 | 117 | 87.5 | 98.8 | 108 | 104 |
| | mean | | 114 | 115 | 87.7 | 95.6 | 109 | 101 |
| | std dev | | 10.8 | 6.74 | 1.87 | 7.88 | 0.66 | 2.52 |
| Marlow | FF-HIGH | 1 | 90.1 | 182 | 170 | 70.4 | 101 | 115 |
| Marlow | FF-HIGH | 2 | 101 | 140 | 128 | 85.3 | 103 | 111 |
| Marlow | FF-HIGH | 3 | 99.0 | 176 | 129 | 77.6 | 105 | 112 |
| | mean | | 96.7 | 166 | 142 | 77.8 | 103 | 113 |
| | std dev | | 5.88 | 22.4 | 24.0 | 7.49 | 2.13 | 1.94 |
| Success | FF-HIGH | 1 | 158 | 154 | 113 | 97.8 | 119 | 117 |
| Success | FF-HIGH | 2 | 170 | 182 | 139 | 84.8 | 100 | 104 |
| Success | FF-HIGH | 3 | 161 | 168 | 126 | 83.1 | 96.1 | 97.1 |
| | mean | | 163 | 168 | 126 | 88.6 | 105 | 106 |
| | std dev | | 6.17 | 14.1 | 12.8 | 8.04 | 12.4 | 9.9 |
| Lombard | FF-HIGH | 1 | 61.2 | 77.1 | 63.7 | 203 | 232 | 240 |
| Lombard | FF-HIGH | 2 | 68.2 | 75.2 | 77.5 | 201 | 227 | 233 |
| Lombard | FF-HIGH | 3 | 68.6 | 73.0 | 76.3 | 202 | 214 | 231 |
| | mean | | 66.0 | 75.1 | 72.5 | 202 | 224 | 234 |
| | std dev | | 4.18 | 2.04 | 7.62 | 0.94 | 9.27 | 4.58 |

DOC OUTFLOW SOLUTION DATA FOR COLUMN STUDY 2.

| parent material | solution | # | DOC DATA mg/L run 1 | run 2 | run 3 |
|---|---|---|---|---|---|
| Hermon | FF-LOW | 1 | 13.9 | 13.1 | 15.7 |
| Hermon | FF-LOW | 2 | 12.7 | 12.5 | 15.2 |
| Hermon | FF-LOW | 3 | 11.5 | 11.5 | 15.5 |
| | mean | | 12.7 | 12.4 | 15.5 |
| | std dev | | 1.2 | 0.8 | 0.3 |
| Marlow | FF-LOW | 1 | 10.6 | 11.1 | 16.0 |
| Marlow | FF-LOW | 2 | 10.7 | 9.9 | 13.8 |
| Marlow | FF-LOW | 3 | 6.3 | 6.0 | 14.1 |
| | mean | | 9.2 | 9.0 | 14.6 |
| | std dev | | 2.5 | 2.7 | 1.2 |
| Success | FF-LOW | 1 | 13.2 | 13.9 | 10.4 |
| Success | FF-LOW | 2 | 13.6 | 14.4 | 17.0 |
| Success | FF-LOW | 3 | 13.2 | 12.8 | 18.3 |
| | mean | | 13.3 | 13.7 | 15.3 |
| | std dev | | 0.2 | 0.8 | 4.3 |
| Lombard | FF-LOW | 1 | 12.6 | 13.1 | 18.1 |
| Lombard | FF-LOW | 2 | 12.6 | 12.3 | 16.5 |
| Lombard | FF-LOW | 3 | 11.3 | 12.2 | 15.5 |
| | mean | | 12.2 | 12.5 | 16.7 |
| | std dev | | 0.8 | 0.5 | 1.3 |
| Hermon | FF-MEDIUM | 1 | 55.6 | 61.3 | 74.0 |
| Hermon | FF-MEDIUM | 2 | 54.4 | 59.2 | 65.0 |
| Hermon | FF-MEDIUM | 3 | 51.8 | 58.4 | 67.1 |
| | mean | | 53.9 | 59.6 | 68.7 |
| | std dev | | 1.9 | 1.5 | 4.7 |
| Marlow | FF-MEDIUM | 1 | 42.5 | 61.2 | 78.4 |
| Marlow | FF-MEDIUM | 2 | 37.5 | 56.5 | 73.7 |
| Marlow | FF-MEDIUM | 3 | 27.4 | 52.6 | 68.5 |
| | mean | | 35.8 | 56.8 | 73.6 |
| | std dev | | 7.7 | 4.3 | 5.0 |

DOC DATA
mg/L

| parent material | solution | # | run 1 | run 2 | run 3 |
|---|---|---|---|---|---|
| Success | FF-MEDIUM | 1 | 53.9 | 66.4 | 70.2 |
| Success | FF-MEDIUM | 2 | 55.6 | 65.1 | 72.5 |
| Success | FF-MEDIUM | 3 | 50.6 | 71.4 | 77.7 |
| | mean | | 53.4 | 67.6 | 73.5 |
| | std dev | | 2.5 | 3.3 | 3.8 |
| Lombard | FF-MEDIUM | 1 | 54.3 | 72.5 | 74.2 |
| Lombard | FF-MEDIUM | 2 | 56.3 | 70.7 | 76.1 |
| Lombard | FF-MEDIUM | 3 | 55.6 | 65.0 | 85.2 |
| | mean | | 55.4 | 69.4 | 78.5 |
| | std dev | | 1.0 | 3.9 | 5.9 |
| Hermon | FF-HIGH | 1 | 104 | 141 | 141 |
| Hermon | FF-HIGH | 2 | 110 | 134 | 136 |
| Hermon | FF-HIGH | 3 | 105 | 127 | 139 |
| | mean | | 106 | 134 | 139 |
| | std dev | | 3.4 | 7.1 | 2.2 |
| Marlow | FF-HIGH | 1 | 68.1 | 121 | 162 |
| Marlow | FF-HIGH | 2 | 79.1 | 120 | 163 |
| Marlow | FF-HIGH | 3 | 71.7 | 124 | 172 |
| | mean | | 73.0 | 122 | 165 |
| | std dev | | 5.6 | 2.4 | 5.6 |
| Success | FF-HIGH | 1 | 113 | 138 | 145 |
| Success | FF-HIGH | 2 | 99.3 | 135 | 158 |
| Success | FF-HIGH | 3 | 98.6 | 122 | 153 |
| | mean | | 103 | 131 | 152 |
| | std dev | | 7.8 | 8.6 | 6.4 |
| Lombard | FF-HIGH | 1 | 102 | 128 | 137 |
| Lombard | FF-HIGH | 2 | 116 | 127 | 139 |
| Lombard | FF-HIGH | 3 | 122 | 130 | 141 |
| | mean | | 113 | 128 | 139 |
| | std dev | | 10.0 | 1.5 | 2.0 |

IRON AND MAGNESIUM OUTFLOW SOLUTION DATA FOR COLUMN STUDY 2.

| parent material | solution | # | IRON DATA µmol/L run 1 | run 2 | run 3 | MAGNESIUM DATA µmol/L run 1 | run 2 | run 3 |
|---|---|---|---|---|---|---|---|---|
| Hermon | DW | 1 | 0.14 | 0.05 | 0.00 | 3.70 | 1.19 | 0.74 |
| Hermon | DW | 2 | 0.32 | 1.20 | 0.29 | 4.48 | 0.82 | 0.33 |
| Hermon | DW | 3 | 0.36 | 0.68 | 0.13 | 3.70 | 1.03 | 0.53 |
| | mean | | 0.27 | 0.61 | 0.14 | 3.96 | 1.01 | 0.53 |
| | std dev | | 0.12 | 0.63 | 0.14 | 0.45 | 0.19 | 0.21 |
| Marlow | DW | 1 | 0.05 | 0.18 | 0.95 | 6.21 | 1.19 | 0.82 |
| Marlow | DW | 2 | 0.23 | 0.14 | 3.28 | 6.83 | 1.03 | 1.32 |
| Marlow | DW | 3 | 0.09 | 0.18 | 6.52 | 7.04 | 0.78 | 2.92 |
| | mean | | 0.07 | 0.17 | 3.58 | 6.69 | 1.00 | 1.69 |
| | std dev | | 0.16 | 0.02 | 2.80 | 0.43 | 0.21 | 1.10 |
| Success | DW | 1 | 0.73 | 4.33 | 0.16 | 4.53 | 3.79 | 0.37 |
| Success | DW | 2 | 0.29 | 0.90 | 0.82 | 6.42 | 1.28 | 0.45 |
| Success | DW | 3 | 0.05 | 2.06 | 0.73 | 6.67 | 1.44 | 0.41 |
| | mean | | 0.36 | 2.43 | 0.57 | 5.87 | 2.17 | 0.41 |
| | std dev | | 0.35 | 1.75 | 0.36 | 1.17 | 1.40 | 0.04 |
| Lombard | DW | 1 | 3.92 | 8.20 | 0.27 | 7.41 | 6.30 | 2.39 |
| Lombard | DW | 2 | 3.27 | 1.13 | 0.56 | 6.09 | 4.85 | 2.47 |
| Lombard | DW | 3 | 7.58 | 1.13 | 2.20 | 5.18 | 4.44 | 3.09 |
| | mean | | 4.92 | 3.49 | 1.01 | 6.23 | 5.20 | 2.65 |
| | std dev | | 1.90 | 4.08 | 1.04 | 1.12 | 0.97 | 0.38 |
| Hermon | HNO3 | 1 | 13.9 | 0.81 | 0.59 | 7.41 | 1.85 | 1.11 |
| Hermon | HNO3 | 2 | 3.72 | 0.70 | 0.56 | 6.09 | 1.85 | 1.03 |
| Hermon | HNO3 | 3 | 2.42 | 0.93 | 0.63 | 5.18 | 1.73 | 0.99 |
| | mean | | 6.67 | 0.81 | 0.59 | 6.23 | 1.81 | 1.04 |
| | std dev | | 6.27 | 0.12 | 0.04 | 1.12 | 0.07 | 0.06 |
| Marlow | HNO3 | 1 | 0.79 | 1.31 | 0.63 | 7.12 | 1.73 | 1.44 |
| Marlow | HNO3 | 2 | 0.18 | 1.07 | 0.82 | 8.02 | 1.56 | 1.23 |
| Marlow | HNO3 | 3 | 0.72 | 0.81 | 0.54 | 8.93 | 1.93 | 1.52 |
| | mean | | 0.56 | 1.06 | 0.66 | 8.02 | 1.74 | 1.40 |
| | std dev | | 0.33 | 0.25 | 0.15 | 0.91 | 0.19 | 0.15 |
| Success | HNO3 | 1 | 1.29 | 1.02 | 0.90 | 8.02 | 1.93 | 1.44 |
| Success | HNO3 | 2 | 0.98 | 0.57 | 0.57 | 9.83 | 1.52 | 1.36 |
| Success | HNO3 | 3 | 0.84 | 0.61 | 0.66 | 9.79 | 1.56 | 1.44 |
| | mean | | 1.04 | 0.73 | 0.71 | 9.22 | 1.67 | 1.41 |
| | std dev | | 0.23 | 0.25 | 0.17 | 1.03 | 0.23 | 0.05 |

| parent material | solution | # | IRON DATA µmol/L run 1 | run 2 | run 3 | MAGNESIUM DATA µmol/L run 1 | run 2 | run 3 |
|---|---|---|---|---|---|---|---|---|
| Lombard | HNO3 | 1 | 0.75 | 0.68 | 0.97 | 83.1 | 106 | 111 |
| Lombard | HNO3 | 2 | 1.43 | 0.50 | 0.43 | 73.6 | 105 | 109 |
| Lombard | HNO3 | 3 | 1.43 | 0.41 | 0.47 | 67.1 | 93.0 | 88.9 |
| | mean | | 1.21 | 0.53 | 0.62 | 74.6 | 101 | 103 |
| | std dev | | 0.39 | 0.14 | 0.30 | 8.07 | 7.38 | 12.1 |
| Hermon | FF-LOW | 1 | 3.29 | 2.24 | 0.95 | 7.20 | 4.32 | 3.62 |
| Hermon | FF-LOW | 2 | 6.80 | 3.38 | 0.95 | 6.71 | 4.03 | 3.62 |
| Hermon | FF-LOW | 3 | 4.98 | 2.06 | 0.88 | 6.38 | 3.41 | 2.67 |
| | mean | | 5.03 | 2.56 | 0.93 | 6.76 | 3.92 | 3.31 |
| | std dev | | 1.76 | 0.72 | 0.04 | 0.41 | 0.46 | 0.55 |
| Marlow | FF-LOW | 1 | 2.40 | 2.56 | 1.84 | 10.5 | 5.51 | 4.77 |
| Marlow | FF-LOW | 2 | 1.02 | 1.56 | 0.82 | 9.63 | 4.16 | 3.62 |
| Marlow | FF-LOW | 3 | 0.21 | 1.90 | 2.95 | 9.26 | 3.46 | 3.46 |
| | mean | | 1.21 | 2.01 | 1.87 | 9.79 | 4.37 | 3.95 |
| | std dev | | 1.10 | 0.51 | 1.07 | 0.63 | 1.05 | 0.72 |
| Success | FF-LOW | 1 | 8.09 | 3.21 | 1.25 | 9.09 | 4.77 | 3.74 |
| Success | FF-LOW | 2 | 5.28 | 6.39 | 1.74 | 9.18 | 5.14 | 3.46 |
| Success | FF-LOW | 3 | 5.34 | 3.78 | 1.56 | 8.97 | 3.74 | 2.63 |
| | mean | | 6.24 | 4.46 | 1.52 | 9.08 | 4.55 | 3.28 |
| | std dev | | 1.61 | 1.70 | 0.24 | 0.10 | 0.72 | 0.58 |
| Lombard | FF-LOW | 1 | 39.2 | 4.15 | 1.99 | 18.8 | 13.4 | 10.0 |
| Lombard | FF-LOW | 2 | 14.5 | 5.21 | 2.31 | 12.5 | 11.6 | 8.35 |
| Lombard | FF-LOW | 3 | 15.6 | 6.25 | 1.58 | 11.6 | 9.75 | 6.75 |
| | mean | | 23.1 | 5.20 | 1.96 | 14.3 | 11.6 | 8.38 |
| | std dev | | 14.0 | 1.05 | 0.37 | 3.92 | 1.83 | 1.65 |
| Hermon | FF-MEDIUM | 1 | 14.3 | 11.7 | 3.76 | 18.7 | 17.6 | 16.7 |
| Hermon | FF-MEDIUM | 2 | 11.0 | 11.2 | 3.76 | 17.0 | 16.2 | 15.6 |
| Hermon | FF-MEDIUM | 3 | 13.4 | 12.2 | 3.63 | 18.3 | 15.6 | 14.1 |
| | mean | | 12.9 | 11.7 | 3.72 | 18.0 | 16.5 | 15.5 |
| | std dev | | 1.75 | 0.49 | 0.07 | 0.91 | 1.05 | 1.34 |
| Marlow | FF-MEDIUM | 1 | 8.92 | 13.1 | 4.24 | 23.2 | 20.1 | 17.8 |
| Marlow | FF-MEDIUM | 2 | 6.18 | 9.47 | 4.24 | 20.0 | 17.2 | 16.9 |
| Marlow | FF-MEDIUM | 3 | 2.61 | 15.3 | 3.80 | 19.3 | 18.4 | 16.6 |
| | mean | | 5.90 | 12.6 | 4.09 | 20.8 | 18.6 | 17.1 |
| | std dev | | 3.16 | 2.94 | 0.26 | 2.07 | 1.49 | 0.61 |

| parent material | solution | # | IRON DATA µmol/L run 1 | run 2 | run 3 | MAGNESIUM DATA µmol/L run 1 | run 2 | run 3 |
|---|---|---|---|---|---|---|---|---|
| Success | FF-MEDIUM | 1 | 14.5 | 11.6 | 4.03 | 20.6 | 17.9 | 17.4 |
| Success | FF-MEDIUM | 2 | 13.7 | 11.0 | 3.67 | 18.3 | 15.9 | 16.5 |
| Success | FF-MEDIUM | 3 | 13.2 | 13.1 | 3.89 | 19.4 | 16.5 | 16.5 |
| | mean | | 13.8 | 11.9 | 3.86 | 19.4 | 16.7 | 16.8 |
| | std dev | | 0.65 | 1.07 | 0.18 | 1.15 | 1.01 | 0.48 |
| Lombard | FF-MEDIUM | 1 | 27.9 | 17.6 | 6.97 | 38.1 | 39.0 | 39.3 |
| Lombard | FF-MEDIUM | 2 | 19.9 | 18.8 | 8.31 | 34.6 | 41.6 | 35.7 |
| Lombard | FF-MEDIUM | 3 | 21.7 | 14.9 | 6.93 | 35.4 | 38.6 | 35.1 |
| | mean | | 23.2 | 17.1 | 7.40 | 36.1 | 39.7 | 36.7 |
| | std dev | | 4.23 | 1.99 | 0.79 | 1.84 | 1.60 | 2.25 |
| Hermon | FF-HIGH | 1 | 22.9 | 22.7 | 7.91 | 30.7 | 32.4 | 32.5 |
| Hermon | FF-HIGH | 2 | 22.4 | 22.9 | 8.06 | 31.8 | 32.0 | 32.3 |
| Hermon | FF-HIGH | 3 | 22.6 | 23.8 | 8.09 | 33.0 | 32.0 | 33.3 |
| | mean | | 22.6 | 23.2 | 8.02 | 31.8 | 32.1 | 32.7 |
| | std dev | | 0.27 | 0.58 | 0.09 | 1.17 | 0.23 | 0.56 |
| Marlow | FF-HIGH | 1 | 8.06 | 18.1 | 9.92 | 31.9 | 33.6 | 39.0 |
| Marlow | FF-HIGH | 2 | 12.4 | 21.5 | 8.06 | 33.6 | 32.8 | 39.5 |
| Marlow | FF-HIGH | 3 | 11.0 | 24.5 | 8.42 | 32.5 | 34.2 | 38.1 |
| | mean | | 10.5 | 21.4 | 8.80 | 32.7 | 33.5 | 38.9 |
| | std dev | | 2.23 | 3.22 | 0.99 | 0.85 | 0.72 | 0.67 |
| Success | FF-HIGH | 1 | 24.9 | 25.4 | 8.72 | 35.8 | 36.7 | 39.1 |
| Success | FF-HIGH | 2 | 23.3 | 24.0 | 9.02 | 34.6 | 31.7 | 35.5 |
| Success | FF-HIGH | 3 | 20.8 | 24.0 | 8.29 | 33.8 | 30.3 | 33.2 |
| | mean | | 23.0 | 24.5 | 8.68 | 34.7 | 32.9 | 35.9 |
| | std dev | | 2.08 | 0.83 | 0.37 | 1.00 | 3.35 | 2.95 |
| Lombard | FF-HIGH | 1 | 30.4 | 28.5 | 14.1 | 62.1 | 64.6 | 66.7 |
| Lombard | FF-HIGH | 2 | 31.2 | 26.7 | 17.1 | 60.9 | 63.4 | 62.1 |
| Lombard | FF-HIGH | 3 | 28.1 | 26.0 | 14.7 | 59.2 | 59.2 | 60.5 |
| | mean | | 29.9 | 27.0 | 15.3 | 60.8 | 62.4 | 63.1 |
| | std dev | | 1.59 | 1.29 | 1.59 | 1.44 | 2.80 | 3.20 |

SILICA AND POTASSIUM OUTFLOW SOLUTION DATA FOR COLUMN STUDY 2.

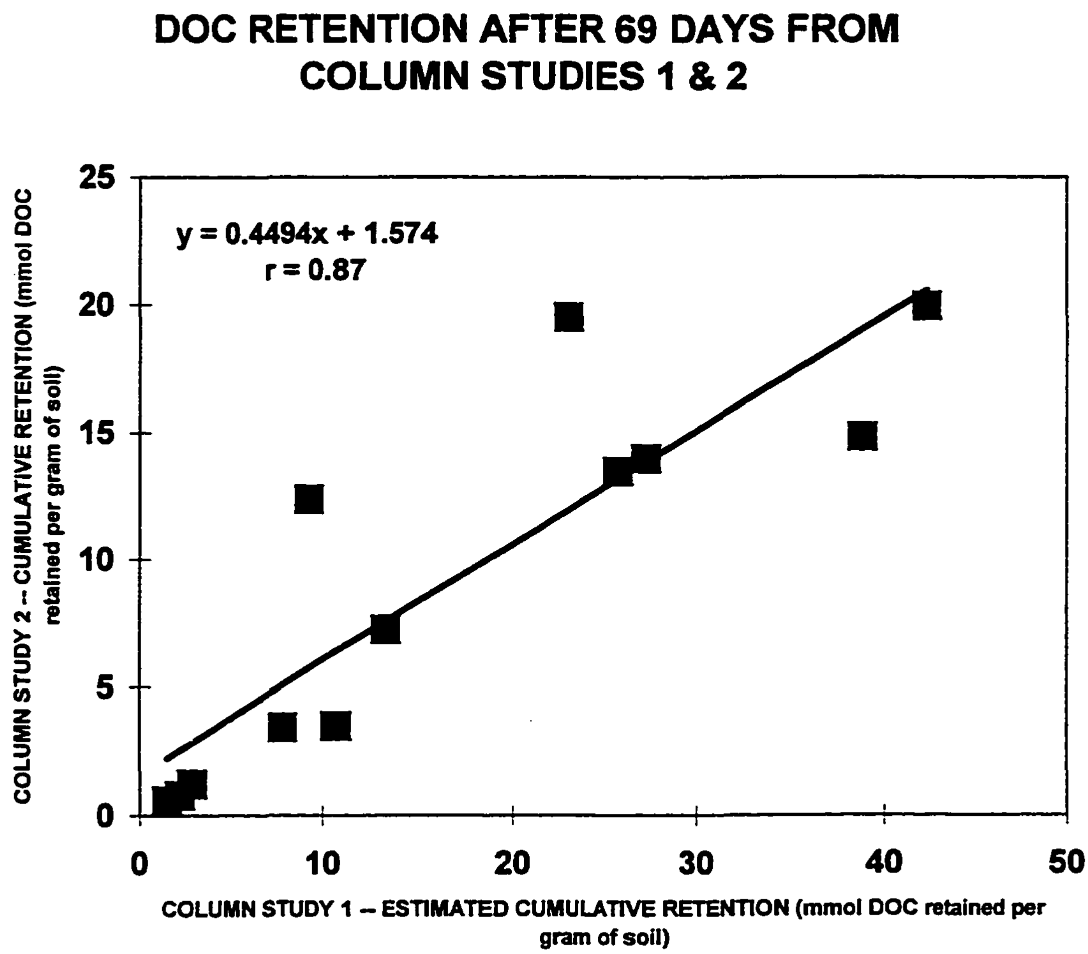
| | | | SILICA DATA µmol/L | | | POTASSIUM DATA µmol/L | | |
|---|---|---|---|---|---|---|---|---|
| parent material | solution | # | run 1 | run 2 | run 3 | run 1 | run 2 | run 3 |
| Hermon | DW | 1 | 47.9 | 29.1 | 17.2 | 24.3 | 10.4 | 8.11 |
| Hermon | DW | 2 | 64.5 | 35.0 | 22.1 | 29.2 | 12.7 | 9.72 |
| Hermon | DW | 3 | 54.8 | 32.1 | 20.4 | 24.0 | 10.2 | 8.57 |
| | mean | | 55.7 | 32.1 | 19.9 | 25.8 | 11.1 | 8.80 |
| | std dev | | 8.32 | 2.91 | 2.48 | 2.90 | 1.42 | 0.83 |
| Marlow | DW | 1 | 92.5 | 53.5 | 32.8 | 14.1 | 8.44 | 5.24 |
| Marlow | DW | 2 | 117 | 55.6 | 35.2 | 16.4 | 9.51 | 7.47 |
| Marlow | DW | 3 | 114 | 55.3 | 37.0 | 15.1 | 9.90 | 10.7 |
| | mean | | 108 | 54.8 | 35.0 | 15.2 | 9.28 | 7.81 |
| | std dev | | 13.3 | 1.17 | 2.12 | 1.18 | 0.76 | 2.75 |
| Success | DW | 1 | 64.3 | 40.2 | 21.3 | 25.0 | 13.8 | 7.01 |
| Success | DW | 2 | 89.5 | 47.3 | 29.5 | 37.1 | 14.6 | 6.78 |
| Success | DW | 3 | 91.7 | 51.0 | 31.6 | 39.4 | 13.4 | 6.68 |
| | mean | | 81.8 | 46.2 | 27.5 | 33.8 | 13.9 | 6.82 |
| | std dev | | 15.2 | 5.48 | 5.47 | 7.75 | 0.58 | 0.17 |
| Lombard | DW | 1 | 47.5 | 38.3 | 23.8 | 17.5 | 15.0 | 10.2 |
| Lombard | DW | 2 | 52.4 | 39.8 | 25.2 | 17.2 | 14.3 | 11.1 |
| Lombard | DW | 3 | 59.9 | 47.5 | 30.9 | 16.5 | 15.4 | 10.4 |
| | mean | | 53.3 | 41.9 | 26.6 | 17.1 | 14.9 | 10.5 |
| | std dev | | 6.26 | 4.94 | 3.78 | 0.52 | 0.55 | 0.48 |
| Hermon | HNO3 | 1 | 69.8 | 54.7 | 51.4 | 17.5 | 28.6 | 15.4 |
| Hermon | HNO3 | 2 | 69.6 | 49.7 | 49.0 | 17.2 | 25.1 | 16.3 |
| Hermon | HNO3 | 3 | 71.6 | 47.5 | 51.5 | 16.5 | 23.4 | 14.7 |
| | mean | | 70.3 | 50.6 | 50.6 | 17.1 | 25.7 | 15.4 |
| | std dev | | 1.09 | 3.66 | 1.44 | 0.52 | 2.68 | 0.79 |
| Marlow | HNO3 | 1 | 109 | 73.3 | 70.7 | 36.6 | 24.1 | 12.2 |
| Marlow | HNO3 | 2 | 113 | 67.8 | 67.1 | 36.3 | 17.8 | 12.3 |
| Marlow | HNO3 | 3 | 110 | 70.1 | 75.5 | 34.8 | 17.2 | 13.7 |
| | mean | | 111 | 70.4 | 71.1 | 35.9 | 19.7 | 12.8 |
| | std dev | | 2.20 | 2.74 | 4.24 | 0.97 | 3.86 | 0.85 |

| parent material | solution | # | SILICA DATA µmol/L run 1 | run 2 | run 3 | POTASSIUM DATA µmol/L run 1 | run 2 | run 3 |
|---|---|---|---|---|---|---|---|---|
| Success | HNO3 | 1 | 91.7 | 55.0 | 54.0 | 51.9 | 26.1 | 13.2 |
| Success | HNO3 | 2 | 115 | 69.4 | 69.1 | 67.5 | 22.1 | 12.0 |
| Success | HNO3 | 3 | 109 | 65.9 | 67.3 | 62.7 | 22.3 | 12.8 |
| | mean | | 105 | 63.4 | 63.5 | 60.7 | 23.5 | 12.7 |
| | std dev | | 12.1 | 7.55 | 8.24 | 7.98 | 2.25 | 0.60 |
| Lombard | HNO3 | 1 | 85.8 | 63.1 | 66.3 | 57.5 | 60.4 | 59.3 |
| Lombard | HNO3 | 2 | 67.4 | 58.6 | 59.1 | 54.0 | 72.6 | 69.8 |
| Lombard | HNO3 | 3 | 66.8 | 55.9 | 64.1 | 47.1 | 57.0 | 52.9 |
| | mean | | 73.3 | 59.2 | 63.2 | 52.9 | 63.3 | 60.7 |
| | std dev | | 10.8 | 3.65 | 3.70 | 5.33 | 8.22 | 8.52 |
| Hermon | FF-LOW | 1 | 53.2 | 34.8 | 25.8 | 33.2 | 27.4 | 26.6 |
| Hermon | FF-LOW | 2 | 53.2 | 31.3 | 22.3 | 33.2 | 25.5 | 24.4 |
| Hermon | FF-LOW | 3 | 63.1 | 39.1 | 25.9 | 33.0 | 26.3 | 22.0 |
| | mean | | 56.5 | 35.1 | 24.7 | 33.2 | 26.4 | 24.3 |
| | std dev | | 5.69 | 3.90 | 2.06 | 0.15 | 0.93 | 2.30 |
| Marlow | FF-LOW | 1 | 88.1 | 49.0 | 32.7 | 25.6 | 26.3 | 25.5 |
| Marlow | FF-LOW | 2 | 95.8 | 57.3 | 39.4 | 20.7 | 24.2 | 21.9 |
| Marlow | FF-LOW | 3 | 120 | 59.3 | 43.7 | 26.9 | 28.6 | 17.0 |
| | mean | | 101 | 55.2 | 38.6 | 24.4 | 26.4 | 21.5 |
| | std dev | | 16.6 | 5.43 | 5.53 | 3.25 | 2.23 | 4.27 |
| Success | FF-LOW | 1 | 63.9 | 34.9 | 24.0 | 41.7 | 32.0 | 27.9 |
| Success | FF-LOW | 2 | 85.8 | 41.9 | 29.6 | 46.5 | 34.8 | 24.8 |
| Success | FF-LOW | 3 | 85.2 | 49.4 | 32.4 | 47.1 | 29.2 | 22.9 |
| | mean | | 78.3 | 42.1 | 28.7 | 45.1 | 32.0 | 25.2 |
| | std dev | | 12.5 | 7.28 | 4.30 | 2.96 | 2.81 | 2.51 |
| Lombard | FF-LOW | 1 | 54.2 | 38.5 | 28.6 | 26.6 | 26.6 | 22.6 |
| Lombard | FF-LOW | 2 | 57.0 | 45.0 | 30.0 | 21.6 | 22.0 | 20.1 |
| Lombard | FF-LOW | 3 | 68.0 | 49.1 | 36.8 | 20.3 | 20.0 | 18.8 |
| | mean | | 59.7 | 44.2 | 31.8 | 22.8 | 22.9 | 20.5 |
| | std dev | | 7.31 | 5.35 | 4.42 | 3.31 | 3.39 | 1.93 |

| parent material | solution | # | SILICA DATA µmol/L run 1 | run 2 | run 3 | POTASSIUM DATA µmol/L run 1 | run 2 | run 3 |
|---|---|---|---|---|---|---|---|---|
| Hermon | FF-MEDIUM | 1 | 79.8 | 46.5 | 43.0 | 76.2 | 74.9 | 93.4 |
| Hermon | FF-MEDIUM | 2 | 85.2 | 50.8 | 47.3 | 68.3 | 71.1 | 90.5 |
| Hermon | FF-MEDIUM | 3 | 88.7 | 50.7 | 47.9 | 156 | 73.4 | 84.9 |
| | mean | | 84.6 | 49.4 | 46.1 | 100 | 73.1 | 89.6 |
| | std dev | . | 4.47 | 2.47 | 2.65 | 48.7 | 1.93 | 4.30 |
| Marlow | FF-MEDIUM | 1 | 111 | 61.4 | 55.3 | 66.2 | 79.5 | 89.5 |
| Marlow | FF-MEDIUM | 2 | 123 | 65.2 | 61.4 | 60.6 | 74.4 | 89.0 |
| Marlow | FF-MEDIUM | 3 | 138 | 74.6 | 65.5 | 66.2 | 73.7 | 81.6 |
| | mean | | 124 | 67.1 | 60.8 | 64.4 | 75.9 | 86.7 |
| | std dev | | 13.8 | 6.77 | 5.11 | 3.25 | 3.20 | 4.44 |
| Success | FF-MEDIUM | 1 | 101 | 52.1 | 47.4 | 80.6 | 76.7 | 96.4 |
| Success | FF-MEDIUM | 2 | 94.8 | 51.0 | 46.4 | 71.6 | 66.8 | 89.8 |
| Success | FF-MEDIUM | 3 | 120 | 57.8 | 51.4 | 87.2 | 68.3 | 89.3 |
| | mean | | 106 | 53.6 | 48.4 | 79.8 | 70.6 | 91.8 |
| | std dev | | 13.3 | 3.62 | 2.64 | 7.83 | 5.37 | 4.00 |
| Lombard | FF-MEDIUM | 1 | 97.4 | 55.6 | 53.8 | 49.9 | 54.5 | 72.4 |
| Lombard | FF-MEDIUM | 2 | 96.4 | 59.8 | 65.5 | 48.6 | 54.2 | 68.8 |
| Lombard | FF-MEDIUM | 3 | 94.0 | 58.3 | 59.0 | 46.5 | 54.5 | 71.6 |
| | mean | | 96.0 | 57.9 | 59.4 | 48.3 | 54.4 | 70.9 |
| | std dev | | 1.72 | 2.14 | 5.83 | 1.68 | 0.15 | 1.89 |
| Hermon | FF-HIGH | 1 | 133 | 72.9 | 80.3 | 123 | 127 | 173 |
| Hermon | FF-HIGH | 2 | 127 | 70.0 | 79.6 | 121 | 127 | 183 |
| Hermon | FF-HIGH | 3 | 126 | 68.7 | 77.4 | 131 | 126 | 193 |
| | mean | | 128 | 70.5 | 79.1 | 125 | 127 | 183 |
| | std dev | | 3.60 | 2.16 | 1.51 | 5.61 | 0.26 | 10.4 |
| Marlow | FF-HIGH | 1 | 168 | 97.1 | 91.7 | 106 | 128 | 201 |
| Marlow | FF-HIGH | 2 | 156 | 83.4 | 92.7 | 159 | 121 | 190 |
| Marlow | FF-HIGH | 3 | 160 | 82.8 | 88.1 | 101 | 130 | 190 |
| | mean | | 161 | 87.8 | 90.8 | 122 | 126 | 194 |
| | std dev | | 6.05 | 8.11 | 2.41 | 32.2 | 4.94 | 6.35 |

| parent material | solution | # | SILICA DATA µmol/L run 1 | run 2 | run 3 | POTASSIUM DATA µmol/L run 1 | run 2 | run 3 |
|---|---|---|---|---|---|---|---|---|
| Success | FF-HIGH | 1 | 144 | 76.0 | 77.5 | 123 | 149 | 220 |
| Success | FF-HIGH | 2 | 165 | 84.6 | 81.4 | 125 | 132 | 197 |
| Success | FF-HIGH | 3 | 173 | 89.9 | 91.8 | 127 | 122 | 183 |
| | mean | | 161 | 83.5 | 83.6 | 125 | 134 | 200 |
| | std dev | | 15.4 | 7.02 | 7.37 | 1.68 | 13.3 | 19.1 |
| Lombard | FF-HIGH | 1 | 157 | 102 | 122 | 70.6 | 94.4 | 131 |
| Lombard | FF-HIGH | 2 | 147 | 103 | 127 | 81.8 | 92.3 | 130 |
| Lombard | FF-HIGH | 3 | 143 | 98.1 | 133 | 83.9 | 89.3 | 116 |
| | mean | | 149. | 101 | 127 | 78.8 | 92.0 | 126 |
| | std dev | | 7.22 | 2.65 | 5.69 | 7.16 | 2.57 | 8.06 |

# APPENDIX B: FIELD AND BATCH STUDIES


DOC RETENTION AFTER 69 DAYS FROM COLUMN STUDIES 1 & 2
y = 0.4494x + 1.574
r = 0.87
COLUMN STUDY 2 -- CUMULATIVE RETENTION (mmol DOC retained per gram of soil)
COLUMN STUDY 1 -- ESTIMATED CUMULATIVE RETENTION (mmol DOC retained per gram of soil)
0
5
10
15
20
25
30
40
50

Pedon Descriptions for Jericho Pond Road Site, Berlin, NH – May-June 1996

| | | | |
|---|---|---|---|
| Site: | 1 | Location: | East side, site closest to road |
| Vegetation: | Balsam fir dominant, lycopodium on ground, some maples | | |
| Climate: | frigid | | |
| Parent material: | glacial till | | |
| Physiography: | shoulder | | |
| Relief: | hummocky due to tip ups and boulders | | |
| Drainage: | well drained | | |
| Slope: | 1-2% | | |
| % Coarse fragments: | 30-40% cobbles and stones | | |
| Permeability: | moderate to slow | | |

Additional Notes:

Site 1 has a moderate pan in the BC horizon. Much less evident than in Site 2, but more than Site 3.
There is some compaction in the O horizons due to its close proximity to the throughway to other sites.
Pan begins at 45 cm in the BC horizon.

| Horizon | depth cm | moist color | texture | structure | consistence | boundary | % gravel | % cobbles | roots |
|---|---|---|---|---|---|---|---|---|---|
| O | 7 | | | | | | | | mvf,mf,fm |
| E | 18 | 7.5 YR 5/2 | fsl | 2sbk | fr | a | | | mf, cm |
| Bhs | 27 | 5 YR 3/3 | fsl | 2sbk | 6 | a to c | | | cf |
| Bs | 45 | 7.5 YR 5/6 | fsl | 2m-1sbk | fi to fr | c | < 20 | <15 | |
| BCm | 45+ | 7.5 YR 3/4 | gr to vgr lcos | 3m-parting to single grained | vfi to fi | c | <20 | <25 | |

Pedon Descriptions for Jericho Pond Road Site, Berlin, NH – May-June 1996

| | | | |
|---|---|---|---|
| Site: | 2 | Location: | East side, site 2nd closest to road |
| Vegetation: | Balsam fir dominant | | |
| Climate: | frigid | | |
| Parent material: | glacial till | | |
| Physiography: | shoulder | | |
| Relief: | hummocky due to tip ups and boulders | | |
| Drainage: | well drained | | |
| Slope: | 3-4% | | |
| % Coarse fragments: | 30% cobbles and stones | | |
| Permeability: | moderate to slow | | |

Additional Notes:

B(h)s horizons are wavy and discontinuous, along the lower edge of the Bs top of BCm
there are many decaying roots (looks almost like a Bhs)
O has so many vf roots included that it was difficult to sample
No description or samples from BCm, could not break apart the pan.

| Horizon | depth cm | moist color | texture | structure | consistence | boundary | % gravel | % cobbles | roots |
|---|---|---|---|---|---|---|---|---|---|
| O | 4 | | | | | | | | mvf,mf,fm |
| E | 11 | 10 YR 6/1 | fsl | 2sbk | fr | c | 5 | 10 | mf, cm |
| Bhs | 32 | 7.5 YR 4/6 | fsl | 2sbk | fr | c | 15 | 20 | cf |
| Bs | 46 | 10 YR 4/6 | fsl | 2sbk | fr | c | 20 | 15 | |
| BCm | 46+ | | | | | | | | |

Pedon Descriptions for Jericho Pond Road Site, Berlin, NH -- May-June 1996

| | | | |
|---|---|---|---|
| Site: | 3 | Location: | East side, furthest from road |
| Vegetation: | Balsam fir dominant | | |
| Climate: | frigid | | |
| Parent material: | glacial till | | |
| Physiography: | shoulder | | |
| Relief: | hummocky due to tip ups and boulders | | |
| Drainage: | well drained | | |
| Slope: | 3-5% | | |
| % Coarse fragments: | 10% cobbles and stones | | |
| Permeability: | good to moderate | | |

Additional Notes:

E is discontinuous and wavy, was not sampled or described

Thin Bhs also present in localized areas, was not described or sampled

| Horizon | depth cm | moist color | texture | structure | consistence | boundary | % gravel | % cobbles | roots |
|---|---|---|---|---|---|---|---|---|---|
| O | 8 | | | | | | | | mvf, mf |
| E | -- | | | | | | | | cm, mf |
| $Bs_1$ | 23 | 7.5 YR 3/4 | fsl | 2sbk | fr | gr | <2 | <10 | cm |
| $Bs_2$ | 38 | 7.5 YR 4/8 | fsl | 1&2sbk<br>2abk | fr | c | <2 | 10 | cf |
| BCm | 38+ | 10 YR 4/6 | fsl | 2sbk | fr | | <10 | | |

Pedon Descriptions for Jericho Pond Road Site, Berlin, NH -- May-June 1996

| | | | |
|---|---|---|---|
| Site: | 4 | Location: | West side southern-most site |
| Vegetation: | Balsam fir dominant | | |
| Climate: | frigid | | |
| Parent material: | glacial till | | |
| Physiography: | shoulder | | |
| Relief: | hummocky due to tip ups and boulders | | |
| Drainage: | well drained | | |
| Slope: | 5% | | |
| % Coarse frags: | 10% cobbles and stones | | |
| Permeability: | moderate to slow | | |

| Horizon | depth cm | moist color | texture | structure | consistence | boundary | % gravel | % cobbles | roots |
|---|---|---|---|---|---|---|---|---|---|
| O | 8 | | | | | | | | mvf, mf |
| E | 15 | 10 YR 4/1 | fsl | 2sbk | fr | c | 10 | 2-5 | mf, fm |
| Bs | 57 | 7.5 YR 3/4 | fsl | 2sbk | fr | g | 5 | 2-5 | cm, cf |
| BC | 57+ | 10 YR 5/6 | ls | s gr | l, g | | 5 | 10 | |

Pedon Descriptions for Jericho Pond Road Site, Berlin, NH – May-June 1996

| | | | |
|---|---|---|---|
| Site: | 5 | Location: | West side, closest to main road |
| Vegetation: | Balsam fir dominant | | |
| Climate: | frigid | | |
| Parent material: | glacial till | | |
| Physiography: | shoulder | | |
| Relief: | hummocky due to tip ups and boulders | | |
| Drainage: | well drained | | |
| Slope: | 3-5% | | |
| % Coarse fragments: | 20% cobbles and stones | | |
| Permeability: | good to moderate | | |

Additional Notes:

BCm – three different colors, pockety. In some places looks like Bsm, but the lighter, reddish/brown color dominates.

Colors are taken without the sun.

| Horizon | depth cm | moist color | texture | structure | consistence | boundary | % gravel | % cobbles | roots |
|---|---|---|---|---|---|---|---|---|---|
| O | 14 | | | | | | | | mvf, mf, fm |
| E | 20 | 2.5 Y 5/2 | lfs | 2sbk | fr | a | | 2-5 | |
| Bh | 23 | 2.5 YR 2.5/1 | fsl | 2sbk | fr | a | | 2-5 | mf, fm |
| Bhs | 38 | 5 YR 3/2 | fsl | 2sbk | fr/fi | a | >5 | 10 | cm, fm |
| Bs | 50 | 7.5 YR 3/3 | lfs | 2sbk | fi/vfi | c | >10 | 10 | cf |
| BCm | 50+ | 7.5 YR 4/3 | slcos | ma | efi | | >10 | 10-15 | |

Pedon Descriptions for Jericho Pond Road Site, Berlin, NH – May-June 1996

| | | | |
|---|---|---|---|
| Site: | 6 | Location: | West side, central site, furthest from road |
| Vegetation: | Balsam fir dominant | | |
| Climate: | frigid | | |
| Parent material: | glacial till | | |
| Physiography: | shoulder | | |
| Relief: | hummocky due to tip ups and boulders | | |
| Drainage: | well drained | | |
| Slope: | 10-15% | | |
| % Coarse fragments: | 10-15% cobbles and stones | | |
| Permeability: | good to moderate | | |

Additional Notes:

horizons are variable throughout the pit.

Bhs streak down opposite side of described face of pit.

Some Bs was massive, but majority was not

| Horizon | depth cm | moist color | texture | structure | consistence | boundary | % gravel | % cobbles | roots |
|---|---|---|---|---|---|---|---|---|---|
| O | 10 | 7.5 YR 2.5/1 | | | | | | | mvf, mf, fm |
| E | 15 | 2.5 Y 5/2 | ls | 2sbk | fr | c | | 10 | mf, cm |
| Bhsm | 22 | 2.5 YR 2.5/3 | ls | ma | vfi | c | | 5 | cm |
| Bs | 62 | 7.5 YR 4/6 | ls | 2sbk | fi/vfi | c | <10 | 10 | cf |
| BCm | 62+ | 7.5 YR 4/4 | ls | ma | efi | g | 10 | 10 | |

TEXTURE AND PARTICLE SIZE DISTRIBUTION FOR BERLIN FIELD SITES
DATA IN PERCENT

| site | horizon | texture | clay | silt | sand | f. sil | c. sil. | vfs | fs | ms | cs | vcs |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | E | SL | 2.5 | 37.4 | 60.1 | 15.1 | 22.3 | 12.3 | 17.5 | 15.4 | 9.8 | 5.1 |
| 1 | Bhs | SL | 2.7 | 32.6 | 64.7 | 11.9 | 20.7 | 13.6 | 19.2 | 15.5 | 11.1 | 5.3 |
| 1 | Bs | SL | 1.6 | 29.2 | 69.2 | 11.4 | 17.8 | 12.4 | 19.6 | 17.9 | 11.4 | 7.9 |
| 1 | BCm | LCOS | 1.3 | 13.2 | 85.5 | 5.3 | 7.9 | 10.1 | 23.6 | 22.7 | 19.2 | 9.9 |
| 2 | E | FSL | 2.1 | 39.9 | 58.0 | 15.9 | 24.0 | 13.0 | 17.1 | 15.2 | 7.8 | 4.9 |
| 2 | Bhs | FSL | 1.8 | 38.3 | 59.9 | 13.9 | 24.4 | 14.9 | 17.8 | 14.6 | 8.6 | 4.0 |
| 2 | Bs | LCOS | 1.1 | 19.5 | 79.4 | 7.4 | 12.1 | 10.9 | 21.1 | 21.1 | 14.2 | 12.1 |
| 3 | Bhs | FSL | 1.5 | 46.0 | 52.5 | 16.2 | 29.8 | 14.1 | 15.7 | 11.8 | 7.2 | 3.7 |
| 3 | Bs | FSL | 1.7 | 43.5 | 54.8 | 16.0 | 27.5 | 16.4 | 17.4 | 12.2 | 6.3 | 2.5 |
| 3 | BC | FSL | 1.9 | 42.3 | 55.8 | 15.7 | 26.6 | 13.3 | 15.9 | 12.4 | 7.5 | 6.7 |
| 4 | E | LCOS | 2.1 | 24.2 | 73.7 | 9.8 | 14.4 | 8.7 | 18.3 | 21.3 | 14.9 | 10.5 |
| 4 | Bs | SL | 2.5 | 26.5 | 71.0 | 11.2 | 15.3 | 10.1 | 16.8 | 19.5 | 14.9 | 9.7 |
| 4 | BC | COS | 1.1 | 9.9 | 89.0 | 3.4 | 6.5 | 7.6 | 21.7 | 27.4 | 19.2 | 13.1 |
| 5 | E | SL | 1.6 | 27.1 | 71.3 | 11.5 | 15.6 | 8.9 | 16.9 | 21.4 | 14.2 | 9.9 |
| 5 | Bhs | LCOS | 1.2 | 19.4 | 79.4 | 9.1 | 10.3 | 8.3 | 16.9 | 21.8 | 20.4 | 12.0 |
| 5 | Bs | LCOS | 1.3 | 16.1 | 82.6 | 7.5 | 8.6 | 6.8 | 14.8 | 21.3 | 22.7 | 17.0 |
| 5 | BCm | COS | 1.1 | 6.1 | 92.8 | 2.2 | 3.9 | 4.2 | 13.5 | 31.6 | 34.6 | 8.9 |
| 6 | E | LCOS | 1.5 | 18.1 | 80.4 | 7.5 | 10.6 | 9.1 | 21.6 | 23.8 | 14.9 | 11.0 |
| 6 | Bhsm | LCOS | 1.0 | 15.1 | 83.9 | 6.0 | 9.1 | 4.3 | 17.1 | 22.9 | 22.1 | 17.5 |
| 6 | Bs | COS | 1.4 | 8.5 | 90.1 | 3.4 | 5.1 | 5.0 | 15.3 | 23.9 | 27.2 | 18.7 |
| 6 | BCm | COS | 0.9 | 8.4 | 90.7 | 3.7 | 4.7 | 4.0 | 11.5 | 21.5 | 27.7 | 26.0 |

SOIL CHEMICAL DATA FROM THE SIX PEDONS AT THE BERLIN, NH FIELD SITE

| SITE | HORIZON | org. C | Fed | Ald | -NH4 Extractable Bases- Ca | Mg | Na | K | Sum | Acidity | Ext. Al | sum cats | NH4- OAC | bases +Al | Al sat | base sum | pH 0.01M CaCl2 | pH water |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | ---- % ---- | | | ---- cmol / kg ---- | | | | | | | | | | ---- % ---- | | 1:2 | 1:1 |
| 1 | E | 1.08 | 0.3 | 0.1 | 0.6 | 0.1 | 0.1 | 0.1 | 0.9 | 8.3 | 2.6 | 9.2 | 6.4 | 3.5 | 74 | 10 | 3.2 | 3.7 |
| 1 | BHS | 7.79 | 2.8 | 2 | 0.6 | 0.1 | 0.1 | 0.1 | 0.9 | 68.2 | 8.4 | 69.1 | 42.0 | 9.3 | 90 | 1 | 4.1 | 4.6 |
| 1 | BS | 3.84 | 1.6 | 1.5 | 0.5 | tr | tr | tr | 0.5 | 41.0 | 1.4 | 41.5 | 23.1 | 1.9 | 74 | 1 | 4.5 | 5 |
| 1 | BCM | 2.01 | 0.5 | 0.6 | 0.2 | -- | tr | tr | 0.2 | 21.3 | 0.2 | 21.5 | 8.3 | 0.4 | 50 | 1 | 4.4 | 5.3 |
| 2 | E | 1.58 | 0.2 | 0.1 | 0.4 | 0.1 | tr | 0.1 | 0.6 | 9.5 | 0.1 | 10.1 | 8.0 | 0.7 | 14 | 6 | 3.3 | 3.8 |
| 2 | BS1 | 5.04 | 2.3 | 1.6 | 0.3 | 0.1 | tr | 0.1 | 0.5 | 50.5 | 0.6 | 51.0 | 30.7 | 1.1 | 55 | 1 | 4.2 | 4.7 |
| 2 | BS2 | 1.94 | 0.6 | 0.5 | 0.1 | tr | tr | tr | 0.1 | 19.7 | 0.6 | 19.8 | 10.1 | 0.7 | 86 | 1 | 4.4 | 4.9 |
| 3 | BHS | 5.06 | 2.1 | 1.7 | 0.4 | 0.1 | tr | 0.1 | 0.6 | 44.4 | 0.1 | 45.0 | 26.2 | 0.7 | 14 | 1 | 4.3 | 4.9 |
| 3 | BS | 3.57 | 2.9 | 1.6 | 0.1 | tr | tr | tr | 0.1 | 38.0 | 0.4 | 38.1 | 17.3 | 0.5 | 80 | tr | 4.5 | 4.9 |
| 3 | BC | 2.35 | 1.7 | 1 | 0.2 | tr | tr | tr | 0.2 | 25.0 | 0.4 | 25.2 | 11.5 | 0.6 | 67 | 1 | 4.8 | 5.1 |
| 4 | E | 1.41 | 0.1 | 0.1 | 0.2 | 0.1 | tr | 0.1 | 0.4 | 8.4 | 0.1 | 8.8 | 6.5 | 0.5 | 20 | 5 | 3.2 | 3.7 |
| 4 | BS | 2.72 | 1.6 | 0.8 | 0.2 | 0.1 | tr | tr | 0.3 | 30.1 | 1.4 | 30.4 | 15.8 | 1.7 | 82 | 1 | 4.3 | 4.7 |
| 4 | BC | 0.69 | 0.6 | 0.2 | 0.1 | tr | tr | tr | 0.1 | 6.8 | 0.1 | 6.9 | 3.0 | 0.2 | 50 | 1 | 4.5 | 5.1 |
| 5 | E | 1 | 0.3 | 0.1 | 0.4 | 0.1 | tr | tr | 0.5 | 8.1 | 1.8 | 8.6 | 7.1 | 2.3 | 78 | 6 | 3 | 3.5 |
| 5 | BHS | 7.34 | 1.6 | 1.6 | 0.3 | 0.1 | 0.1 | 0.1 | 0.6 | 59.0 | 4.2 | 59.6 | 37.9 | 4.8 | 88 | 1 | 4 | 4.5 |
| 5 | BS | 4.24 | 1.2 | 1.2 | 0.2 | 0.1 | tr | tr | 0.3 | 44.3 | 1.3 | 44.6 | 26.3 | 1.6 | 81 | 1 | 4.2 | 4.7 |
| 5 | BCM | 1.08 | 0.3 | 0.4 | 0.1 | tr | tr | tr | 0.1 | 16.6 | 0.2 | 16.7 | 7.9 | 0.3 | 67 | 1 | 4.3 | 4.9 |
| 6 | E | 0.79 | 0.3 | tr | 0.3 | 0.1 | 0.1 | 0.1 | 0.6 | 5.6 | 0.1 | 6.2 | 4.5 | 0.7 | 14 | 10 | 3.2 | 3.7 |
| 6 | BHSM | 3.33 | 1.3 | 0.8 | 0.2 | 0.1 | 0.1 | tr | 0.4 | 34.6 | 3.5 | 35.0 | 23.7 | 3.9 | 90 | 1 | 3.8 | 4.3 |
| 6 | BS | 1.4 | 0.7 | 0.4 | 0.3 | tr | 0.1 | tr | 0.4 | 18.2 | 0.1 | 18.6 | 7.4 | 0.1 | 20 | 2 | 4.3 | 4.9 |
| 6 | BCM | 1.18 | 0.4 | 0.2 | 0.3 | tr | 0.1 | tr | 0.4 | 9.3 | 0.1 | 9.7 | 5.1 | 0.5 | 20 | 4 | 4.3 | 4.8 |

Volume of lysimeter solutions collected at the Berlin field site.

| DATE | data in mL<br>950822 | 960530 | 960615 | 960702 | 960716 | 961026 | 970619 | 970711 |
|---|---|---|---|---|---|---|---|---|
| 1A | 0 | 0 | 4.5 | 1.4 | 30.0 | 0 | 3.1 | 7.7 |
| 1B | 4.8 | 0.5 | 6.3 | 2.0 | 47.8 | 4.8 | 0 | 11.9 |
| 2A | 0 | 0 | 0 | 0 | 0.8 | 0.0 | reinstalled | 16.4 |
| 2B | 0 | 5 | 37.4 | 19.7 | 50.0 | 61.8 | 0 | 59.6 |
| 3A | 58.1 | 40.3 | 94.1 | 62.4 | 107 | 57.6 | 61.2 | 73.6 |
| 3B | 3.3 | 2.3 | 5.6 | 3 | 15.1 | 6.0 | 0 | 3.2 |
| 4A | 0 | 4.4 | 8.6 | 4.8 | 16.2 | 0.0 | 13.0 | 8.9 |
| 4B | 3.5 | 9.7 | 43.6 | 24.3 | 30.2 | 27.7 | 22.2 | 31.6 |
| 5A | 1.3 | 48 | 58.1 | 38 | 69.3 | 2.3 | 53.4 | 47.4 |
| 5B | 0 | 0 | 0.2 | 0 | 2.0 | 0.0 | 1.6 | 0 |

Chemistry of lysimeter solutions collected at the Berlin field site

DOC data in mg/L

| DATE | 950822 | 960530 | 960615 | 960702 | 960716 | 961026 | 970619 | 970711 | mean |
|---|---|---|---|---|---|---|---|---|---|
| 1A | n.d.* | n.d. | n.d. | n.d. | 33.5 | n.d. | n.d. | 29.4 | 31.5 |
| 1B | n.d. | n.d. | n.d. | n.d. | 15.9 | 18.2 | n.d. | 16.6 | 16.9 |
| 2A | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | 53.2 | 53.2 |
| 2B | n.d. | n.d. | 4.9 | 4.8 | 4.4 | 4.0 | n.d. | 4.6 | 4.5 |
| 3A | 49.3 | 45.9 | 46.1 | 47.1 | 51.7 | 47.5 | 45.9 | 54.1 | 48.4 |
| 3B | n.d. | n.d. | n.d. | n.d. | 5.2 | 5.4 | n.d. | n.d. | 5.3 |
| 4A | n.d. | n.d. | 80.1 | 74.3 | 65.1 | n.d. | 81.5 | n.d. | 75.3 |
| 4B | n.d. | 19.9 | 16.8 | 18.5 | 16.5 | 17.5 | 17.8 | 15.9 | 17.6 |
| 5A | n.d. | 58.9 | 65.9 | n.d. | 77.3 | 54.9 | 63.1 | 76.1 | 66.0 |
| 5B | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. |

ALUMINUM data in µmol/L

| DATE | 950822 | 960530 | 960615 | 960702 | 960716 | 961026 | 970619 | 970711 | mean |
|---|---|---|---|---|---|---|---|---|---|
| 1A | n.d. | n.d. | 22.5 | 12.7 | 16.8 | n.d. | 20.9 | 15.9 | 17.8 |
| 1B | 23.1 | n.d. | 23.3 | 28.9 | 25.7 | n.d. | n.d. | 29.1 | 26.0 |
| 2A | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | 59.8 | 59.8 |
| 2B | n.d. | 10.4 | 5.7 | 6.6 | 4.9 | 5.5 | n.d. | 6.3 | 6.6 |
| 3A | 54.8 | 57.8 | 57.8 | 78.9 | 61.9 | 63.7 | 59.2 | 78.1 | 64.0 |
| 3B | 10.1 | 10.4 | 9.3 | 11.2 | 7.9 | n.d. | n.d. | 9.4 | 9.7 |
| 4A | n.d. | 59.3 | 63.0 | 93.0 | 74.1 | n.d. | 64.9 | 80.1 | 72.4 |
| 4B | n.d. | 31.5 | 25.6 | 36.8 | 25.5 | 24.9 | 26.6 | 29.1 | 28.6 |
| 5A | 121 | 69.3 | 97.1 | 168 | 127 | n.d. | 87.2 | 135 | 115 |
| 5B | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. |

CALCIUM data in µmol/L

| DATE | 950822 | 960530 | 960615 | 960702 | 960716 | 961026 | 970619 | 970711 | mean |
|---|---|---|---|---|---|---|---|---|---|
| 1A | n.d. | n.d. | 96.3 | 58.4 | 83.1 | n.d. | 76.5 | 82.1 | 79.3 |
| 1B | 27.3 | n.d. | 24.4 | 30 | 29.9 | n.d. | n.d. | 28.7 | 28.1 |
| 2A | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | 18.5 | 18.5 |
| 2B | n.d. | 21.7 | 20.8 | 23.1 | 23.7 | 25.7 | n.d. | 23.6 | 23.1 |
| 3A | 18.2 | 15.3 | 12.9 | 12.8 | 12.3 | 27.5 | 10.9 | 19.2 | 16.1 |
| 3B | 22.1 | 25.7 | 25.9 | 17.7 | 19.0 | n.d. | n.d. | 22.4 | 22.1 |
| 4A | n.d. | 70.1 | 35.2 | 47.6 | 53.7 | n.d. | 39.3 | 68.5 | 52.4 |
| 4B | 57.1 | 53.1 | 61.4 | 69.1 | 60.1 | 34.2 | 61.5 | 55.7 | 56.5 |
| 5A | n.d. | 52.4 | 32.4 | 33.7 | 24.5 | n.d. | 44.8 | 26.5 | 35.7 |
| 5B | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. |

| IRON | data in µmol/L | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| DATE | 950822 | 960530 | 960615 | 960702 | 960716 | 961026 | 970619 | 970711 | mean |
| 1A | n.d. | n.d. | 12.6 | 7.0 | 6.5 | n.d. | 10.6 | 6.9 | 8.7 |
| 1B | 4.6 | n.d. | 5.6 | 4.8 | 3.2 | n.d. | n.d. | 4.3 | 4.5 |
| 2A | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | 7.8 | 7.8 |
| 2B | n.d. | 5.9 | 1.9 | 1.1 | 0.3 | 0.8 | n.d. | 1.4 | 1.9 |
| 3A | 6.7 | 6.8 | 7.6 | 8.5 | 5.1 | 5.3 | 10.1 | 5.2 | 6.9 |
| 3B | 1.4 | 5.4 | 2.5 | 2.8 | 0.8 | n.d. | n.d. | 3.1 | 2.7 |
| 4A | n.d. | 14.9 | 12.5 | 12.9 | 8.8 | n.d. | 13.4 | 9.9 | 12.1 |
| 4B | 3.0 | 7.5 | 2.4 | 2.6 | 0.9 | 1.1 | 5.1 | 0.5 | 2.9 |
| 5A | n.d. | 5.2 | 6.1 | 8.1 | 4.9 | n.d. | 6.3 | 3.6 | 5.7 |
| 5B | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. |

| MAGNESIUM | data in µmol/L | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| DATE | 950822 | 960530 | 960615 | 960702 | 960716 | 961026 | 970619 | 970711 | mean |
| 1A | n.d. | n.d. | 21.4 | 12.8 | 22.7 | n.d. | 14.5 | 22.4 | 18.8 |
| 1B | 14.4 | n.d. | 13.9 | 12.7 | 15.7 | n.d. | n.d. | 14.0 | 14.1 |
| 2A | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | 7.4 | 7.4 |
| 2B | n.d. | 8.6 | 5.1 | 3.6 | 4.0 | 4.9 | n.d. | 4.4 | 5.1 |
| 3A | 2.4 | 3.0 | 2.6 | 1.9 | 2.3 | 3.4 | 3.2 | 1.7 | 2.6 |
| 3B | 4.7 | 6.8 | 5.1 | 3.3 | 4.2 | n.d. | n.d. | 5.1 | 4.9 |
| 4A | n.d. | 42.8 | 29.5 | 25.4 | 22.0 | n.d. | 21.7 | 32.9 | 29.0 |
| 4B | 25.2 | 28.0 | 24.6 | 25.4 | 26.8 | 16.0 | 28.7 | 25.5 | 25.0 |
| 5A | n.d. | 7.4 | 4.4 | 5.7 | 3.6 | n.d. | 3.7 | 4.3 | 4.8 |
| 5B | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. |

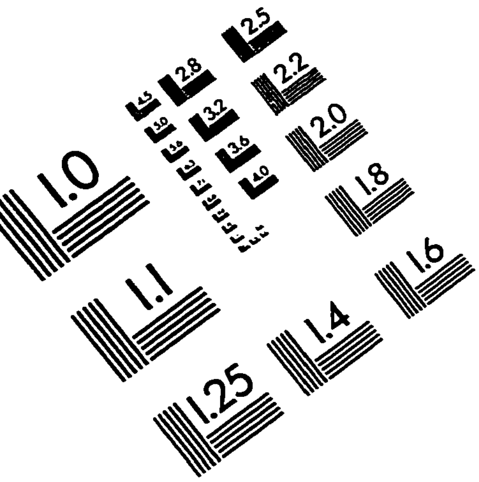
| POTASSIUM | data in µmol/L | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| DATE | 950822 | 960530 | 960615 | 960702 | 960716 | 961026 | 970619 | 970711 | mean |
| 1A | n.d. | n.d. | 64.0 | 45.7 | 29.2 | n.d. | 23.2 | 36.5 | 39.7 |
| 1B | 9.9 | n.d. | 12.7 | 10.8 | 7.0 | n.d. | n.d. | 10.5 | 10.2 |
| 2A | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | 44.5 | 44.5 |
| 2B | n.d. | 28.6 | 5.1 | 3.2 | 2.3 | 1.3 | n.d. | 8.5 | 8.2 |
| 3A | 30.2 | 38.4 | 32.7 | 22.5 | 35.2 | 28.1 | 19.1 | 25.3 | 28.9 |
| 3B | 20.1 | 44.8 | 8.7 | 15.3 | 14.2 | n.d. | n.d. | 19.5 | 20.4 |
| 4A | n.d. | 201 | 39.1 | 27.4 | 40.2 | n.d. | 140 | 27.4 | 79.2 |
| 4B | 50.1 | 79.0 | 21.0 | 46.9 | 58.1 | 62.4 | 28.6 | 53.2 | 49.9 |
| 5A | n.d. | 7.0 | 5.2 | 6.0 | 6.0 | n.d. | 6.1 | 6.5 | 6.1 |
| 5B | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. |

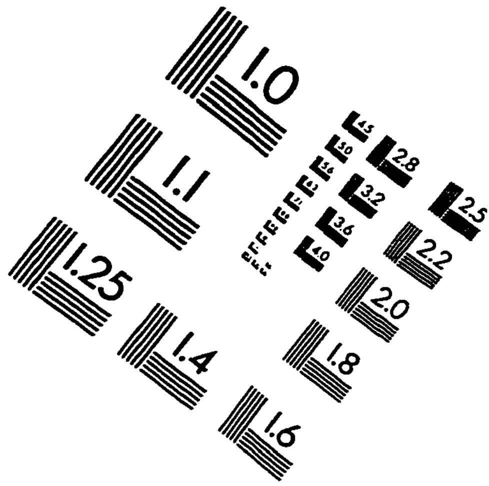
| SILICA | | data in μmol/L | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| DATE | 950822 | 960530 | 960615 | 960702 | 960716 | 961026 | 970619 | 970711 | mean |
| 1A | n.d. | n.d. | 155 | 72.4 | 53.1 | n.d. | 125 | 39.9 | 89.1 |
| 1B | 145 | n.d. | 157 | 178 | 85.2 | n.d. | n.d. | 173 | 148 |
| 2A | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | 145 | 145 |
| 2B | n.d. | 276 | 131 | 164 | 127 | 130 | n.d. | 147 | 162 |
| 3A | 163 | 173 | 143 | 169 | 110 | 106 | 231 | 172 | 158 |
| 3B | 174 | 167 | 134 | 178 | 141 | n.d. | n.d. | 162 | 159 |
| 4A | n.d. | 257 | 155 | 230 | 141 | n.d. | 217 | 165 | 194 |
| 4B | 284 | 229 | 289 | 363 | 348 | 173 | 301 | 254 | 280 |
| 5A | n.d. | 127 | 131 | 292 | 154 | n.d. | 187 | 121 | 169 |
| 5B | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. |

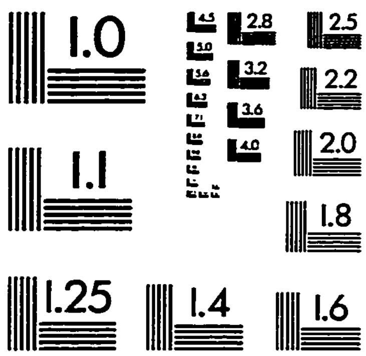
| SODIUM | | data in μmol/L | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| DATE | 950822 | 960530 | 960615 | 960702 | 960716 | 961026 | 970619 | 970711 | mean |
| 1A | n.d. | n.d. | 26.1 | 188 | 24.5 | n.d. | 36.0 | 123 | 79.5 |
| 1B | 35.2 | n.d. | 37.8 | 59.8 | 25.4 | n.d. | n.d. | 26.4 | 36.9 |
| 2A | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | 63.2 | 63.2 |
| 2B | n.d. | 32.6 | 27.9 | 22.8 | 27.1 | 31.8 | n.d. | 21.1 | 27.2 |
| 3A | 20.0 | 12.1 | 17.4 | 18.3 | 22.8 | 24.5 | 17.3 | 23.2 | 19.4 |
| 3B | 51.3 | 81.0 | 43.5 | 52.6 | 39.1 | n.d. | n.d. | 41.9 | 51.6 |
| 4A | n.d. | 288 | 56.0 | 44.4 | 41.5 | n.d. | 132 | 44.1 | 101 |
| 4B | 47.8 | 46.5 | 46.5 | 60.8 | 58.3 | 34.9 | 46.5 | 51.3 | 49.1 |
| 5A | n.d. | 10.2 | 12.3 | 26.4 | 24.2 | n.d. | 12.0 | 25.4 | 18.4 |
| 5B | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. |

*n.d. = not determined due to inadequate volume of sample

# IMAGE EVALUATION TEST TARGET (QA-3)

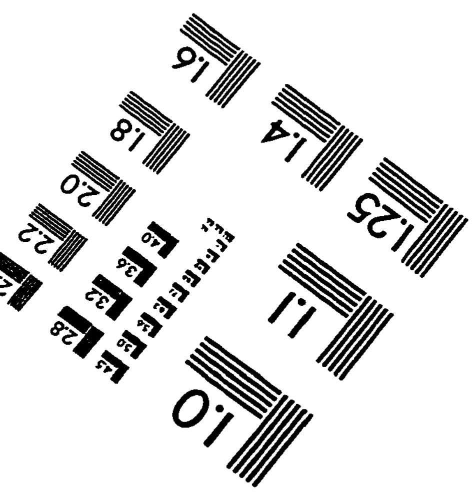


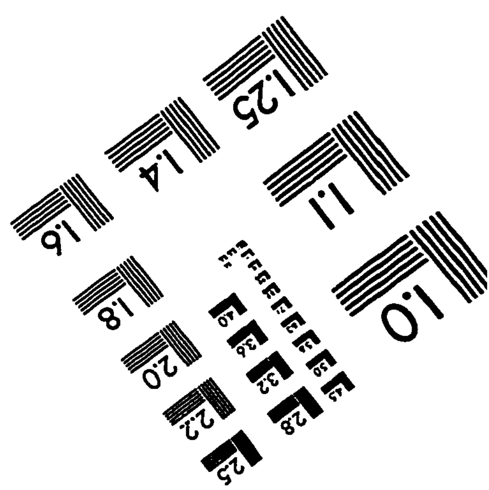




150mm

6"





APPLIED IMAGE, Inc
1653 East Main Street
Rochester, NY 14609 USA
Phone: 716/482-0300
Fax: 716/288-5989